LITHOSTRATIGRAPHY AND CONODONT BIOSTRATIGRAPHY OF THE UPPER BOONE GROUP AND MAYES GROUP IN THE SOUTHWESTERN OZARKS OF OKLAHOMA, MISSOURI, KANSAS, AND ARKANSAS

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LITHOSTRATIGRAPHY AND CONODONT BIOSTRATIGRAPHY OF THE UPPER BOONE GROUP AND MAYES GROUP IN THE SOUTHWESTERN OZARKS OF OKLAHOMA, MISSOURI, KANSAS, AND ARKANSAS

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This degree, assuming it is awarded, will be my third from Oklahoma State University where I began my education and career in geology in the fall of 1995 after taking introductory class and enrolling in structural geology after changing majors several times. Throughout my time at Oklahoma State University, many professors were instrumental in helping shape my understanding and love for geology. Some are no longer with us: Dr. Darwin R. Boardman II, Dr. Zuhair Al-Shaieb, and Dr. Arthur W. Cleaves III. One who still is, and who embodies the mission of the department, is Dr. James O. Puckette. It is because of him that I might earn a paycheck once again, hopefully doing geology. There is a very short list of people with whom I have studied or worked and for whom I have the highest respect and admiration, often because they the bar for which I strive. Jim Puckette is on that list, has been for a long time, and always will be…even if he doesn't want to be, it's a laminated list, I can't change it now.

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Abstract: Upper Boone Group (Meramecian) and Mayes Group (latest Meramecian-Chesterian) strata exposed across the southwestern Ozarks of northeastern Oklahoma, southwestern Missouri, southeastern Kansas, and northwestern Arkansas serve as important analogs for age-equivalent rocks present in the hydrocarbon-producing subsurface of Oklahoma and Kansas to the west and southwest, and they represent important components in the geologic mosaic of the southern Mid-Continent. Through integration of standard lithostratigraphy, conodont biostratigraphy, and modern sequence stratigraphic concepts, an attempt is made to establish an outcrop-based foundation for continuing geologic research concerning this succession, as well as for its correlation into the subsurface and with other strata across the southern Mid-Continent. In terms of results, important changes in lithostratigraphic nomenclature and organization are proposed, including: (1) replacement of the term “Moorefield” by the Pryor Creek Formation (new name) in the Mayes Group of northeastern Oklahoma, (2) removal of the Tahlequah Limestone from the Mayes Group and its inclusion in the Boone Group, (3) elevation of the Moccasin Bend to formation rank, and (4) inclusion of both the Moccasin Bend Formation and Quapaw Limestone in the Boone Group of Mazzullo et al. (2013). Although most of these revisions are based on basic lithostratigraphic methods, conodont biostratigraphic data was valuable in establishing the genetic relationships between strata and correlation of time-equivalent strata across the study area. Conodont biostratigraphic data also provided the basis for establishing preliminary provincial biozones for the study interval and allowed them to be evaluated within the broader context of southern Mid-Continent geology through time-constrained inter-regional correlations. Evidence in the upper Boone Group suggests these strata record continuation of the depositional style characterizing the Osagean Boone Group and that the syndepositional tectonism was a significant factor during their deposition. In the Mayes Group, detailed stratigraphic evaluation highlights the presence of multiple orders of depositional cyclicity. The implications of both syndepositional tectonism during upper Boone Group deposition and depositional cyclicity within the Mayes Group is that reservoir architecture in the subsurface is much more complex, a result of the influence of depositional controls associated with the onset of Late Paleozoic Glaciation and early phases of Ouachita tectonism.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

LIST OF FIGURES

CHAPTER I

CHAPTER II

CHAPTER III

Figure Page

CHAPTER IV

LIST OF PLATES

CHAPTER III

Plate Page

CHAPTER I

GENERAL INTRODUCTION

PROJECT INCEPTION AND PURPOSE

This study began, for me at least, as a simple request in the summer of 2009 to "do some field work" after returning to school following eight years behind a desk working in the oil and gas industry. At the time of my return to school, oil prices and drilling techniques were driving economic and scientific interest in Mississippian reservoirs in the subsurface of Oklahoma and Kansas. In addition to research involving subsurface core data, attention was also being given to Kinderhookian and Osagean outcrop analogs in northeastern Oklahoma, southwestern Missouri, northwestern Arkansas, and southeastern Kansas (Boardman et al., 2013; Mazzullo et al., 2013; Mazzullo et al., 2016; Mazzullo et al., in press). In addition to assisting with the ongoing research regarding Kinderhookian-Osagean strata, I was tasked by my first advisor, the late Dr. Darwin R. Boardman II, with the re-examination of the Meramecian-Chesterian Mayes Group of northeastern Oklahoma. It became apparent during the course of my work on the Mayes Group and the collective investigation of Kinderhookian-Osagean strata that Meramecian strata present in the Tri-State Mining District (Oklahoma-Kansas-Missouri) and Boone County, Arkansas were also poorly-understood and were thus incorporated into my overall investigation. Thus, my dissertation research became a comprehensive stratigraphic study of Meramecian and Chesterian strata within the Mississippian outcrop area and shallow subsurface of Oklahoma, Missouri, Kansas, and Arkansas. The overriding goal of this study is simply the accurate relative age-dating and correlation of these strata, the results of which is the foundation of a biostratigraphically-constrained regional stratigraphic framework within which higher-resolution stratigraphic and sedimentological studies may be incorporated.

PREVIOUS WORK

First defined by Snider (1915), Mayes Group, in its currently accepted form, was formally defined by Huffman (1958). Since then, very little attention has been paid to these rocks in outcrop, most of which has come in the form of graduate theses. Routh (1981) examined three measured sections of the Mayes Group, two of which are included within this study, and processed bulk samples for conodonts from each. Turmelle (1982) examined a number of measured sections Adair County, Oklahoma and Washington County, Arkansas. Shelley (2016) recently completed a thesis at Oklahoma State University concerning exposures within the Pryor Quarry in central Mayes County, Oklahoma, a location that is included within this study. Mohammadi (2016) included samples from this study in her examination of diagenesis of Mississippian strata in Oklahoma, Kansas, and Missouri. Handford (1995) included Mayes Group-equivalent strata within a sequence stratigraphic model in north-central Arkansas. Thompson (1972) reported on conodonts from the Hindsville Formation, Fayetteville Shale, and Pitkin Limestone in Missouri, Oklahoma, and Arkansas. Grayson (1974, 1976) reported on conodonts from the Hindsville Formation of Arkansas. Within the subsurface, the Mayes Group has been recognized by various workers in northern Oklahoma and is considered correlative with the lower Caney Shale (Buchanan, 1927; Cline, 1934; Huffman and Barker, 1950; Elias, 1956; Huffman, 1958; Chenoweth et al., 1959; Heinzelmann, 1964; Huffman et al., 1966; Selk, 1973).

In the Tri-State Mining District, Meramecian strata were defined by McKnight and Fischer (1970) as the Baxter Springs and Moccasin Bend members of their Boone Formation and the Quapaw Limestone. The Boone Group was proposed by Mazzullo et al. (2013) to replace the variety of uses of the term "Boone" in the outcrop area. As a result of this investigation, and as included in Mazzullo et al. (2013), the Ritchey Formation was proposed for Meramecian strata of the Boone Group (typically referred to simply as “Warsaw”) in northern Arkansas and parts of southwestern Missouri (Mazzullo et al., 2013), as well as a replacement for the defunct “Baxter Springs” term in far-northeastern Oklahoma portion of the Tri-State Mining District. Meramecian conodonts of Kansas and the Tri-State Mining District of Oklahoma, Kansas, and Missouri were discussed by Thompson (1972) and Thompson and Goebel (1968). Relatively little has published on conodont fauna of the Moorefield Formation in neither Oklahoma nor Arkansas. Collections assembled by workers from Amoco Research Center during the 1960s were briefly discussed or referenced in several papers (Ormiston, 1966; Selk and Ciriacks, 1968; Selk, 1973; Brenckle et al., 1974). No conodont studies have been published on the Moorefield Formation and Ruddell Shale of northern Arkansas.

Other work concerning the Mississippian section include studies concerning the subsurface of Oklahoma and Kansas (Coffey, 2000; Qi., 2005; Zhao, 2011; Barefoot, 2014; Bertalott, 2014; Cahill, 2014; Houseknecht et al., 2014; Jennings, 2014; Koch et al., 2014; LeBlanc, 2014; Price, 2014; Brown, 2015; Doll, 2015; Lindzey, 2015; Dupont, 2016; Flinton, 2016; Miller, 2016; Thompson, 2016), as well as surface-based studies within the Ozarks focusing on older Mississippian (Kinderhookian-Osagean) strata (Unrast, 2012; Price, 2014; Childress, 2015; Cepero, 2016; Miller, 2016; Mazzullo et al., 2016; OTHERS? U of A.), including studies concerned with conodont biostratigraphy (Shoiea, 2012, Boardman et al., 2013). Several studies have been published concerning timing of diagenetic processes within Mississippian strata (e.g. Coffey, 2000; Rogers, 2001; Young, 2010; Montalvo Lliteras, 2015; Cepero, 2016; Mohammadi, 2016), including in the Tri-State Mining District of Oklahoma, Kansas, and Missouri where lead and zinc mineralization is of economic, as well as environmental, importance (e.g. Ragan, 1996).

STUDY AREA AND METHODS

The study area includes the Mississippian outcrop belt and adjacent shallow subsurface in northeastern Oklahoma, southwestern Missouri, southeastern Kansas, and northwestern Arkansas (Figure 1). Within the study area, 42 stratigraphic sections were measured and described from outcrop locations (including multiple sections in large quarries) and 9 subsurface cores (Table 1). For biostratigraphic analysis bulk samples of at least two kilograms (or more) were taken from each outcrop section. The coarsest sampling interval used was meter-scale, with detail across significant lithologic changes. Higher-resolution sampling was applied at some locations and was, in some cases bed-by-bed. Samples from cores were taken at regular intervals of sub-meter scale, while accounting for lithologic boundaries. In all, our current collection includes specimen from 298 bulk samples from the Mayes Group, 291 bulk samples from the Meramecian Boone Group. Oriented hand samples were taken to be slabbed and for the creation of 445 thin sections for petrographic analysis to supplement descriptions from measured sections.

The processing of bulk carbonates and shale samples for the recovery of conodonts for biostratigraphic analysis follows that of Collinson (1963). For limestone and dolomite bulk samples of at two kilograms were manually disaggregated into cubes no larger than 3 cm. The sample was then placed into a solution of 1 liter of water and 110 milliliters of formic acid per 100 grams of sample. The samples were left to chemically digest for approximately twenty-four hours after which the remaining solution was diluted with water and sieved using a combination of 35 and 120 mesh sieves. The recovered insoluble residues from both the 35 and 120 mesh sieves were then dried overnight at 200 degrees Fahrenheit. The dry residues were then picked through and all fragments and whole conodont elements were counted and collected on micropaleontological slides for analysis. In the case of most dolomite samples the undissolved sample remaining after sieving was dried, weighed, and reprocessed using the appropriate ration of water and formic acid. For argillaceous limestone this same re-processing procedure was followed. Shale samples were likewise manually disaggregated and two kilogram samples weighed. The shale samples were then covered with hydrogen peroxide and left to react. Some samples reacted quickly, some slowly, and others not at all. Once the reaction ended the solution and samples could then be diluted with water and sieved using the 35 and 120 mesh sieves and dried overnight. Most shale samples required multiple runs. Calcareous shale samples were first processed using the formic acid procedure to remove any calcite cement that could hinder the hydrogen peroxide breakdown.

OVERVIEW OF SUBSEQUENT CHAPTERS AND SUPPORTING DATA

The following chapters each represent a stand-alone manuscript, two of which have been submitted for publication in a peer-reviewed memoir to be published by the American Association of Petroleum Geologists (AAPG). The final chapter, Chapter V, constitutes the general summary and conclusions of this study as a whole. Systematic paleontological descriptions of important conodont form species are given in Appendix A. Detailed conodont recoveries are provided for sections sampled are given in Appendix B, with measured stratigraphic sections and sample positions illustrated in Appendix C. Detailed location information for all sections examined is provided in Appendix D.

Chapter II is a paper documenting proposed revisions to the lower Mayes Group. In this chapter, the abandonment of the term "Moorefield Formation" for the lower Mayes Group, as defined in Oklahoma by Huffman (1958), is proposed. In its place, the term "Pryor Creek Formation" is proposed based on exposures in central Mayes County, Oklahoma, the original Mayes Group type area of Snider (1915) and Huffman (1958). Furthermore, it is recommended that the "Tahlequah Member", the basal member of the "Moorefield" of Oklahoma as defined by Huffman (1958), be removed from the Mayes Group and included within the Boone Group. It was originally planned for this paper to be submitted to the Oklahoma City Geological Society's publication, the Shale Shaker, in order to establish the name "Pryor Creek Formation" prior to its application in subsequent manuscript submittals. Poor timing in terms of submitting this paper on the part of this author resulted in the shelving of this manuscript for submittal. Issues of lithostratigraphic nomenclature are thus included within the following manuscript (i.e. Chapter III of this dissertation).

Chapter III primarily concerns conodont biostratigraphy of the Mayes Group and upper Boone Group, but, as was previously mentioned, issues concerning lithostratigraphic revisions to the Mayes Group are also included in this chapter. Additional lithostratigraphic issues within the upper Boone Group, primarily the inclusion of the Moccasin Bend Formation and Quapaw Limestone within Boone Group as defined by Mazzullo et al. (2013) from which those two units were excluded pending further evaluation. The primary purposes of this chapter, aside from the lithostratigraphic revisions, included the documentation of and discussion of conodont recoveries from the Mayes Group and upper Boone Group and the subsequent construction of a preliminary conodont biostratigraphic zonation for these strata. Resultant conodont biostratigraphic data provided the foundation for more confident time-constrained correlations of these strata within the study area, as well as with time-equivalent strata in the southern mid-continent and Upper Mississippi River Valley (i.e. type Mississippian).

Chapter IV concerns observed lithologic, or depositional, cyclicity within the Mayes Group, primarily within Mayes County, but also throughout the study area of northeastern Oklahoma. Three orders of depositional cycles are recognized. The Mayes Group as a whole represents a single shallowing-upward succession or primary transgressive-regressive depositional cycle consisting of two secondary transgressive-regressive depositional cycles. High-frequency

Currently both Chapter III and Chapter IV are in review and consideration for inclusion in the AAPG memoir titled “Mississippian Reservoirs of the Mid-Continent, U.S.A.” edited by G.M. Grammer, J.M. Gregg, J.O. Puckette, P. Jaiswal, M. Pranter, S.J. Mazzullo, and R.H. Goldstein. Chapter III is awaiting submittal of the third, and hopefully final, version. Therefore, the Chapter III paper included within this dissertation is most likely in its final form. First revisions on Chapter II are ongoing and submission of a second draft is likely in mid to late

November, 2016. It is not expected that this second draft will be accepted without more revisions, so it is uncertain at this time whether or not Chapter II will be included within the aforementioned AAPG memoir. As for Chapter II, it will likely not be submitted for publication as is. Rather, a revised version focusing more on a review of the Mayes Group and upper Boone Group in northeastern Oklahoma is planned and will be submitted to the Shale Shaker at a later date. Simple time constraints prohibit the abandonment of Chapter II in its current form and the writing of a new manuscript.

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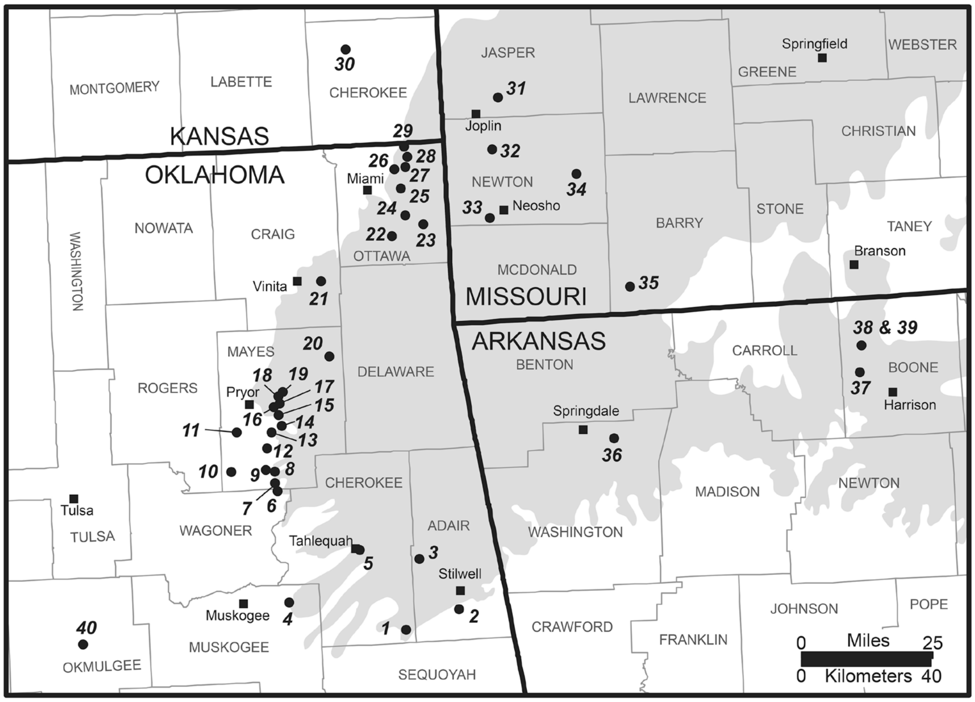
TABLES

Table 1: Location Information

LOCATION NAME	SEC-TWP-RGE	LEGAL SPOT	COUNTY	STATE	LATTITUDE DEG-MIN-SEC (NORTH)	LONGITUDE DEG-MIN-SEC (WEST)
Alpena	22-19N-21W	NW NW	Boone	AR	36 17 36.37	93 12 12.30
Baker Hughes Core BH-1	4-15N-12E	SE NW NE	Okmulgee	OK	35 48 39.91	96 02 16.69
Baxter Springs	16-29N-23E	SW NE	Ottawa	OK	36 59 47.18	94 42 39.44
Bayou Manard Type	19-15N-20E	C SE	Muskogee	OK	35 45 37.16	95 13 6.42
Bicentennial Park	29-29N-24E	E SW NE	Ottawa	OK	36 57 59.19	94 43 40.59
Bidding Creek	17-16N-24E	NE SE NE	Adair	OK	35 52 08.10	94 46 20.28
Big Hollow R.A.	2-18N-19E	SW NE NW	Wagoner	OK	36 04 17.31	95 15 15.34
Burlington North	20-20N-21W	SE NE	Boone	AR	36 22 34.37	93 13 25.33
Burlington South	29-20N-21W	E NE	Boone	AR	36 21 56.37	93 13 28.68
Cedar Creek	21-26N-32W	C SE	Newton	MO	36 57 27.62	94 25 46.84
Cedar Crest Lake	19-19N-19E	E NW NW	Mayes	OK	36 06 59.98	95 13 19.21
Chouteau Bend	27-20N-19E	SW SW SW	Mayes	OK	36 10 39.17	95 16 35.42
Cookson Reference	26-14N-23E	C NW NE	Cherokee	OK	35 39 56.88	94 49 55.22
Devil's Promenade	5-28N-24E	N SW	Ottawa	OK	36 56 8.73	94 44 47.97
Earbob R.A.	35-19N-19E	W SE	Mayes	OK	36 04 41.00	95 15 05.59
Fairland Quarry	11-26N-23E	W SW NW	Ottawa	OK	36 45 6.73	94 48 39.26
Lindsey Bridge Type	6-20N-20E	SW NW SW	Mayes	OK	36 14 22.61	95 13 29.00
Mayes Core M-206	1-21N-19E	SE SE	Mayes	OK	36 19 27.25	95 13 19.19
Mayes Core M-207	10-20N-18E	E NE	Mayes	OK	36 13 56.48	95 22 20.55
Mayes Core M-208	6-21N-20E	NE NW SW	Mayes	OK	36 19 42.65	95 12 56.25
Mayes Core M-209	14-21N-19E	SE SE SE	Mayes	OK	36 17 38.74	95 14 22.51
Mayes Core M-210	13-21N-19E	SW NW NW	Mayes	OK	36 18 17.26	95 14 13.65
Mayes Core M-211	16-19N-18E	E SW	Mayes	OK	36 07 19.43	95 23 42.65
Moccasin Bend Type	30-28N-24E & 31-28N-24E	S SW of Sec 30 & E NW of Sec 31	Ottawa	OK	36 52 21.05	94 45 59.42
MODOT Core B-49-8	20-28N-32W	NE SW NE	Jasper	MO		
Neosho Quarry	24-24-32W	C NW SE	Newton	MO	36 47 44.83	94 26 20.99
Ordnance Plant Type	11 & 14-20N-19E	SE SE of 11 & NE of 14	Mayes	OK	36 13 11.81	95 14 49.82
PM-21 Core	13-32S-22E	NE NE	Cherokee	KS	37 15 54.81	94 56 33.18
Pryor Creek Type (North High-Wall)	25-21N-19E	NE SE	Mayes	OK	36 16 9.94	95 13 16.75
Pryor Creek Type (South High-Wall)	36-21N-19E	SW NE	Mayes	OK	36 15 30.18	95 13 37.83
Quapaw Quarry	1-28N-23E	W SE SW	Ottawa	OK	36 55 49.29	94 46 51.13
Ritchey Type Locality	1-25N-30W & 36-26N-30W	N NW NW of Sec 1 & S SW SE of Sec 36	Newton	MO	36 55 11.84	94 09 41.90
Rock Creek Reference Area	29-23N-20E	N SE SW	Mayes	OK	36 26 26.05	95 11 44.63
Seligman Reference Locality	4-21N-28W	NE SW	Barry	MO	36 33 51.44	93 58 11.72
Spring Creek R.A.	23-19N-19E	W NW	Mayes	OK	36 07 01.84	95 15 22.09
Spring Valley	3-17N-28W	SE NE NE	Washington	AR	36 10 29.35	93 56 31.37
Stilwell Quarry	4-14N-25E	NW NW SE	Adair	OK	35 43 03.37	94 39 21.41
Sycamore Creek	35-27N-24E	N SW	Ottawa	OK	36 46 37.7	94 41 37.75
Tahlequah	4-16N-22E	NW SE NE	Cherokee	OK	35 53 42.09	94 58 10.06
Twin Bridges Section A	29-27N-24E	NE NE	Ottawa	OK	36 47 59.53	94 45 19.48
Twin Bridges Section B	20-27N-24E	S SE	Ottawa	OK	36 48 7.09	94 45 24.71
Vinita Quarry	21-25N-21E	NE	Craig	OK	36 38 24.39	95 03 26.32

FIGURES



1 - Cookson Reference Locality
2 - Stilwell Quarry Reference Locality
3 - Bidding Creek Reference Locality
4 - Bayou Manard Type Locality
5 - Tahlequah Principal Reference Locality
6 - Big Hollow R.A. Reference Locality
7 - Earbob R.A. Reference Locality
8 - Cedar Crest Lake Reference Locality
9 - SPring Creek R.A. Reference Locality
10 - Mayes Core M-211
11 - Mayes Core M-207
12 - Chouteau Bend Reference Locality
13 - Ordnance Plant Type Locality
14 - Lindsey Bridge Type Locality
15 - Pryor Creek Type Locality
16 - Mayes Core M-209
17 - Mayes Core M-210
18 - Mayes Core M-206
19 - Mayes Core M-208
20 - Strang Bridge Reference Locality
21 - Vinita Quarry Reference Locality
22 - Fairland Quarry Reference Locality
23 - Sycamore Creek Reference Locality
24 - Twin Bridges Reference Locality
25 - Moccasin Bend Type Locality
26 - Quapaw Quarry Reference Locality
27 - Devil's Promenade Reference Locality
28 - Bicentennial Park Reference Locality
29 - Baxter Springs Reference Locality
30 - PM-21 Core
31 - MODOT Core B-49-8
32 - Cedar Creek Reference Locality
33 - Neosho Quarry Reference Locality
34 - Ritchey Type Locality
35 - Seligman Reference Locality
36 - Spring Valley Reference Locality
37 - Alpena Reference Locality
38 - Burlington North Reference Locality
39 - Burlington South Reference Locality
40 - Baker Hughes BH-1 Core

Figure 1. Study Area Map

CHAPTER II

THE PROPOSED PRYOR CREEK FORMATION (MAYES GROUP) AND TAHLEQUAH LIMESTONE (BOONE GROUP) OF NORTHEASTERN OKLAHOMA

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ABSTRACT

The Pryor Creek Formation is proposed to replace the obsolete term "Moorefield" for strata of the lower Mayes Group of northeastern Oklahoma. The Pryor Creek Formation is neither contiguous nor lithologically consistent with the type Moorefield Formation of northern Arkansas. Application of the term "Moorefield" in Oklahoma is therefore confusing and irrelevant to strata in Oklahoma, both at the surface and within the subsurface. Defined for exposures along the western edge of the Mississippian outcrop belt in Oklahoma, the Pryor Creek Formation more accurately represents the characteristic shaly-silty limestone and calcareous siltstone-shale of the lower Mayes Group. And, because of its location, the Pryor Creek Formation is a relevant surface analog for correlative strata in the subsurface, including the subsurface "Mayes" and Mississippian "black limestone", with which it is contiguous.

The proposed lithostratigraphic revisions are integrated with modern stratigraphic concepts and conodont biostratigraphic data, resulting in a genetic stratigraphic framework that

may be evaluated within a regional to global context through higher-resolution correlations with time-equivalent strata. Conodont data clearly show that the Pryor Creek Formation is latest Meramecian through early Chesterian in age, correlative to the upper St. Louis Limestone and Ste. Genevieve Formation of the Upper Mississippi Valley, the Ahloso Member of the Caney Shale in southern Oklahoma, and the basal Barnett Shale in Texas, to name a few. The base of the Pryor Creek Formation is a regionally-extensive, time-significant unconformity similar to those recognized below the Caney Shale of southern Oklahoma and Barnett Shale of central Texas. The boundary between the Pryor Creek Formation and overlying Hindsville Formation is conformable. Contacts between recognized lithostratigraphic divisions of the Pryor Creek Formation coincide with sub-regionally to regionally-extensive surfaces.

Conodont biostratigraphic data, together with the revised lithostratigraphic interpretation, also demonstrate that the Tahlequah Limestone (formerly "Tahlequah Member" of the "Moorefield Formation") is separated from the proposed Pryor Creek Formation by a span of time corresponding to at least the lower St. Louis Limestone and is instead faunally and lithologically correlative to the Ritchey Formation of the Boone Group. It is therefore excluded from the proposed Pryor Creek Formation and placed within the Boone Group.

INTRODUCTION

Extensive exposures of the "Moorefield Formation" (lower Mayes Group) in northeastern Oklahoma are integral to our understanding of the Meramecian-Chesterian geologic history of the southern Mid-Continent. And, due to their position along the western edge of the Mississippian outcrop belt, these exposures are critical points of reference and surface analogs for correlative hydrocarbon-producing strata to the west and south in the subsurface of Oklahoma, including the Caney Shale, Mississippian "black limestone", or subsurface "Mayes". Although the "Moorefield Formation" of Oklahoma has long been considered time-correlative to the type Moorefield Formation of northern Arkansas, its use in Oklahoma is problematic due to important lithologic differences between the two stratigraphic units in conjunction with the fact that they are not currently contiguous. Confusion is therefore common when discussing the “Moorefield Formation” in Oklahoma, resulting in the need for constant clarification and thus rendering the use of the term pointless. Furthermore, as currently defined in Oklahoma, the “Moorefield Formation” suffers from application of an antiquated stratigraphic framework consisting of questionable lithostratigraphic nomenclature, organization, genetic relationships, and relative age assignments.

Significant revisions are therefore proposed for the “Moorefield Formation” based on a combination of standard lithostratigraphic methods, modern stratigraphic concepts, and conodont biostratigraphic data. Principal objectives include: (1) reducing confusion associated with the current lithostratigraphic nomenclature through application of new terminology and a designated unit stratotype more representative of this interval in Oklahoma and (2) establishing a time-constrained, genetically-meaningful stratigraphic framework.

Study Area and Background

The study area includes all of Mississippian outcrop area of northeastern Oklahoma where the Mayes Group is known to be exposed (Figure 1), but a specific focus is placed upon the Mayes Group type area of central Mayes County where a concentration of excellent surface exposures and complete shallow subsurface cores are located.

The term “Mayes” was first applied by Snider (1915) to strata between the top of the “Boone formation” and base of the Fayetteville Shale outcropping in Mayes, Wagoner, Cherokee, and Muskogee Counties, Oklahoma (Figure 2). The lower part of the “Mayes” in Oklahoma is historically correlated with the Moorefield Formation of northern Arkansas based on their similar stratigraphic position, macrofauna, and some lithologic similarities (Buchanan, 1927; Cline, 1934; Laudon, 1948; Degraffenreid, 1953; Huffman, 1958; Ogren, 1968). The term “Moorefield” was officially applied in Oklahoma by Huffman (1958) who included it as the lower formation within the Mayes Group. Huffman (1958) designated the upper Mayes Group as the Hindsville Formation, a term also derived from, and correlated to, its type area in northern Arkansas (Purdue and Miser, 1916). Huffman subdivided the "Moorefield Formation" in Oklahoma into four members based on gross lithologic characteristics. In ascending order these are the Tahlequah, Bayou Manard, Lindsey Bridge, and Ordnance Plant members. The Hindsville Formation remained undivided and in Arkansas is considered the lower member of the Batesville Sandstone. The original definition of the "Mayes" by Snider (1915) included only the strata later designated as the upper three members of the "Moorefield Formation" and the Hindsville Formation. Prior to the definition by Huffman (1958), the "Tahlequah Member" was considered the "glauconitic limestone" member of the Keokuk Formation (Degraffenreid, 1953). Other changes have been proposed over the years, but never widely adopted (Brant, 1941; Turmelle, 1982).

The Hindsville Formation is relatively well-constrained regionally using both conodonts (Thompson, 1972; Grayson, 1974, 1976) and ammonoids (McCaleb et al., 1964; Saunders et al., 1977). Outside of this study, we know of only two other sources of conodont data for the "Moorefield Formation" (proposed Pryor Creek Formation) of Oklahoma. First is the Amoco collection, currently stored at the University of Iowa, briefly discussed by Ormiston (1966), Selk and Ciriacks (1968), Selk (1973), and Brenckle et al. (1974), in many cases without significant documentation or illustration. Second is an unpublished thesis by Routh (1981) who examined and sampled three Mayes Group locations in northeastern Oklahoma, including the Lindsey Bridge type locality and Stilwell Quarry locality of this study (Figure 1), and the abandoned Hulbert Quarry (adjacent to the Hulbert locality of this study and location number 103 of Huffman, 1958, p. 217).

Proposed Revisions

Stratigraphic revisions proposed herein include two changes in nomenclature based on a combination of standard lithostratigraphic methods and conodont biostratigraphy, which conform to current provisions of the current North American Code of Stratigraphic Nomenclature (2005). A comparison between previous lithostratigraphic nomenclature and the proposed nomenclature of this report is shown in Figure 2. First, we propose removing the “Tahlequah Member” from the Mayes Group, renaming it the Tahlequah Limestone, and placing it within the Boone Group. This is based on observed lithologic and conodont faunal affinities between the “Tahlequah” and the Ritchey Formation in the Tri-State Mining District (Boardman et al., 2013; Mazzullo et al., 2013). This proposed revision is also predicated upon the separation of the Tahlequah Limestone from the remaining Mayes Group strata by a biostratigraphically-constrained, temporally-significant unconformity. Prior to the inclusion of the “Tahlequah” within the Mayes Group by Huffman (1958), it was considered the informal “glauconitic limestone” member (lower Warsaw-equivalent) of the Keokuk Formation (Bentonville Formation, Boone Group of Mazzullo et al., 2013) (Snider, 1915; Laudon, 1948; Degraffenreid, 1953). Second, we propose abandoning the term “Moorefield” in Oklahoma and replacing it with the “Pryor Creek Formation”. A type locality is proposed in central Mayes County, Oklahoma where the limestone and siltstone-dominated lithology of the Pryor Creek Formation demonstrates a significant departure from that of the type Moorefield Formation of northern Arkansas. Furthermore, because this area is positioned along the western edge of the outcrop belt at the point where these strata dip into the subsurface to the west, it serves as the most proximal surface analog to equivalent productive units in the subsurface of Oklahoma. These nomenclatural revisions are accompanied by the required designation and description of type and principal reference sections.

In addition to the above nomenclature revisions, conodont biostratigraphic data is used to reconcile the revised lithostratigraphy with conodont zonation schemes of Collinson et al. (1971) and Boardman et al. (2013) (Figure 3). Integration of conodont data results in refined relative ages for lithostratigraphic units and construction of a refined regional stratigraphic framework through temporally-constrained correlations. Conodont data also allows these strata to be evaluated within broader inter-regional and global contexts.

TAHLEQUAH LIMESTONE

Principal Reference Locality

The original type section, as defined by Huffman (1958), is poorly exposed along the south bank of Tahlequah Creek (Section 4-T16N-R22E) in the town of Tahlequah in Cherokee County, Oklahoma. The Oklahoma Department of Transportation has graciously provided an excellent exposure within a few hundred feet of the type section (Figure 4). This section, designated the Tahlequah principal reference locality, is situated along west side of the State Highway 10 loop (Figure 4A). A detailed measured section is provided in Figure 4B. Here the unit is 15 feet (4 m) thick and dips to the south as it "drapes" over cherty Osagean Boone Group strata. The Tahlequah Limestone at the principal reference locality consists of thin to medium-bedded, very glauconitic, moderately oolitic, fine to medium-grained bioclastic packstone-grainstone. At the southern end of the exposure, where the unit dips below the surface, upper beds become very thick-bedded. The Tahlequah Limestone is unconformable with underlying cherty limestone of the Boone Group and unconformably overlain by the Bayou Manard Member of the proposed Pryor Creek Formation ("Moorefield Formation) (Figure 4C).

Distribution of Tahlequah Limestone

The Tahlequah Limestone is not widely distributed, bordering on sporadic, and its known occurrences are restricted to parts of Cherokee and northern Sequoyah counties (Huffman, 1958). Routh (1981) interpreted the "Tahlequah" within her Hulbert Quarry location, adjacent to the Hulbert locality of this report (Huffman Location number 103, p. 217). Conodont fauna reported by her for the "Tahlequah" differ from those recovered from the Tahlequah principal reference locality for this study. Huffman (1958, p 217) recognized no "Tahlequah" at his location number 103, nor do we at the Hulbert locality.

Conodont Biostratigraphy and Regional Correlation

Conodont fauna recovered from the Tahlequah Limestone at the principal reference section are characteristic of, and no younger than, the lower part of the *Taphrognathus varians-Apatognathus* Zone of Collinson et al. (1971) (Figure 3). These data, in agreement with the interpretations of previous workers, suggest the Tahlequah Limestone is equivalent to the Warsaw Formation of the Upper Mississippi Valley (Snider, 1915; Degraffenreid, 1953; Huffman, 1958). It does not, however, agree with the assertion by Selk (1973), Brenckle et al. (1974) and Routh (1981) that the Tahlequah Limestone is St. Louis-equivalent. Conodont taxa recovered from the Tahlequah Limestone at the principal reference locality resemble those of the Ritchey Formation of the Boone Group in northeastern Oklahoma, southwestern Missouri, and northern Arkansas, and include *Gnathodus* n. sp. 15 aff. *punctatus*, *Taphrognathus varians*, *Gnathodus pseudosemiglaber*, and *Gnathodus linguiformis* (Boardman et al., 2013; Mazzullo et al., 2013). The Tahlequah Limestone therefore falls within the Upper *texanus-Gnathodus* n. sp. 15 aff. *punctatus* Zone of Boardman et al. (2013). Like the Tahlequah Limestone, the Ritchey Formation (at least within the Tri-State Mining District of Oklahoma) unconformably overlies Osagean Boone Group strata, although no formally-defined conodont zones are known to be missing.

PRYOR CREEK FORMATION (NEW NAME)

Type and Principal Reference Localities

The term “Pryor Creek” is derived from a creek that runs from north to south between the towns of Pryor and Chouteau, Oklahoma (Figure 5). Both the names “Pryor” and “Chouteau” are preoccupied. The proposed Pryor Creek Formation retains, in ascending order, the Bayou Manard, Lindsey Bridge, and Ordnance Plant members of prior usage. The proposed type locality is the Pryor Quarry (Pryor Creek type locality), jointly operated by BuzziUnicem U.S.A. and Kemp Quarries, where it is well exposed in at least two high-wall sections (Figure 6). Within the south high-wall section (Figures 6A and 7), herein designated as the type section, both the lower and upper contacts are exposed. Only the upper contact is exposed in the north high-well section, but the entire overlying Hindsville Formation is well exposed up to the contact with the Fayetteville Shale (Figure 6B). Supplementing the proposed type locality are nearby surface exposures, including the type sections for the Lindsey Bridge Member and Ordnance Plant Member, as well as seven shallow subsurface cores (Mayes cores M-206 through M-211).

The type locality for the Bayou Manard Member, as defined by Huffman (1958), is situated along a tributary of the Arkansas River east of Muskogee, Oklahoma (Figure 8). Because neither the lower nor upper contacts are exposed at this location, it is invalid as a lithostratigraphic type section (North American Code of Stratigraphic Nomenclature, 2005). We therefore propose designating the south high-wall section at the Pryor Creek type locality as the principal reference section for the Bayou Manard Member. The Ordnance Plant type section and Lindsey Bridge type section also serve as valuable reference sections, along with the Mayes County shallow subsurface cores. In all of these instances both contacts are exposed and readily accessible.

The type section for the Lindsey Bridge Member, as defined by Huffman (1958), is located along the north bank of the Grand River southeast of Pryor, Oklahoma in Mayes County (Figure 9). Nearby key reference sections include the Ordnance Plant type section and those within the Pryor Creek type locality.

The Ordnance Plant type section is located along the west bank of the Grand River at the Low Water Dam Public Use Area southeast of Pryor, Oklahoma (Figures 10). Because the Ordnance Plant Member is incompletely exposed at the type locality, Huffman (1958) used an exposure 3.4 miles (5.4 km) to the southwest along the Grand River (Chouteau Bend locality of this study) to complete the composite type section of the unit. The Chouteau Bend locality includes the contact between the Pryor Creek Formation and Hindsville Formation (Figure 10B). Much of the Ordnance Plant Member is now covered by water due to flooding of the Grand River related to the building of the Fort Gibson Dam. On a low river day only the upper five feet (1.5 m) of the Ordnance Plant Member are exposed. We therefore propose designating the Pryor Creek type locality as the principal reference locality for the Ordnance Plant Member because the unit is well exposed in both high-wall sections, along with both contacts.

Sub-Mayes Unconformity

A major regional unconformity, herein called the “sub-Mayes unconformity”, separates the Pryor Creek Formation from underlying strata of various ages. In outcrop, the Pryor Creek Formation most commonly rests on the Osagean Reeds Spring or Bentonville formations of the Boone Group (Figure 7B). This is also the case in the Mayes County shallow subsurface north of the type locality where it overlies either the cherty limestone of the unaltered Reeds Spring Formation or the upper altered phase (Pineville tripolite of Mazzullo et al., 2013) (Figures 11 and 12). At the Ordnance Plant type locality, the Pryor Creek Formation overlies the Bentonville Formation, which, in turn, overlies the Reeds Spring Formation (including Pineville Tripolite) (Figure 13). The Pryor Creek Formation unconformably overlies the lower Meramecian Tahlequah Limestone, where the latter is present (Figure 4C). In the northwestern corner of Sequoyah County, Oklahoma, the Pryor Creek Formation was reported by Huffman (1958, as “Moorefield Formation” undifferentiated) to rest on the Devonian Woodford Shale (as “Chattanooga”) at Strayhorn Landing (Section 10-T13N-R21E; location 3 of Huffman, 1958, p. 117-118). Most of this section, however, is now covered by Tenkiller Lake. In Mayes core M-211, Pryor Creek Formation strata rest on Ordovician strata.

The truncation of Osagean (and Kinderhookian) strata has been discussed by previous workers, and plays an important role in the discussion concerning age and correlations of the

Mississippian, both within the subsurface and from the subsurface to the surface (Buchanan, 1927; Laudon, 1934, 1948; Huffman and Barker, 1950; Huffman, 1956; Selk, 1973).

Similar to the Pryor Creek Formation, both the Caney Shale and Barnett Shale unconformably overlie strata of various ages. Is the northern Lawrence Uplift area of the Arbuckle Uplift (Pontotoc County, Oklahoma), the Caney Shale rests on the Welden Limestone (Osagean), and to the south, it rests on the Woodford Shale (Elias, 1956; Haywa-Branch, 1988). The Barnett Shale unconformably overlies the Chappell Limestone (Osagean) along the northern flank of the Llano Uplift in San Saba County, Texas, and the Ordovician Ellenburger Group, Viola Limestone, or Simpson Group to the north in the subsurface of the Fort Worth Basin (Dott, 1941; Hass, 1953; Montgomery et al., 2005; Singh, 2007).

The base of the Pryor Creek Formation (base of the Bayou Manard Member) is glauconitic and contains phosphatized lithoclasts, fossil debris, and occasional subrounded chert clasts (granule to pebble-sized). Similarly, glauconitic zones are present in the basal Caney Shale. In the southern Arbuckle Uplift area of Oklahoma, the Sycamore Limestone is considered unconformable above the Woodford Shale and is characterized by a glauconitic zone at the base (Fay, 1989). Although the age of the Sycamore Limestone is not as well constrained as that of Caney Shale and Barnett Shale, lithologic and faunal evidence suggest some degree of correlation with the Mayes Group and Caney Shale (Ormiston and Lane, 1976; Schwartzapfel, 1990; Kleehammer, 1991; Coffey, 2000). Early confusion concerning the Sycamore, as well as the Caney Shale, surface “Mayes”, subsurface “Mayes”, and Welden Limestone, is summarized nicely by Braun (1959). A glauconite zone is also present at the base of the “Mississippian Lime” in the subsurface (subsurface “Mayes” or “black limestone”) of Oklahoma (Buchanan, 1927; Heinzelmann, 1964; Krueger, 1965; LeBlanc, 2014). Heinzelmann (1964) reported two glauconite zones in the Payne County, Oklahoma area, one each at the base of the interpreted “Moorefield formation” and “St. Joe Group”. In that report, the most significant lithologic difference between the “Moorefield Formation” and underlying “St. Joe Group” as the increased abundance of silt in the former. As will be discussed later, the Bayou Manard and Lindsey Bridge members of the Pryor Creek Formation are generally less silty than the silt-rich Ordnance Plant Member.

Sub-Unconformity Reservoir Analog

Formation of reservoir-quality Pineville Tripolite facies at the top of the Reeds Spring Formation predates the sub-Mayes unconformity. At the surface, and within the shallow subsurface cores of Mayes County, the preservation of the Pineville Tripolite facies bears an inverse relationship to thickness of the overlying Pryor Creek Formation (Figures 12 and 13). Where the Pryor Creek Formation is thin, the Pineville Tripolite (or younger rock) is preserved below the unconformity, whereas it is typically absent below thicker intervals where the Pryor Creek Formation overlies unaltered cherty limestone of the Reeds Spring Formation or older strata. At the Ordnance Plant type locality, where the Pryor Creek Formation is relatively thin compared with surrounding locations, the Bentonville Formation is present below the sub-Mayes unconformity and overlies Pineville Tripolite. What this demonstrates is that the sub-Mayes unconformity is an important factor in the preservation of potential reservoir facies within the subsurface, and thus should be a consideration in exploration and production models where relevant.

Pryor Creek-Hindsville Contact

The boundary between the Pryor Creek Formation and overlying Hindsville Formation is most readily identified and placed at the transition from the siltstone and shale-dominated interval of the upper Ordnance Plant Member to the skeletal limestone-dominated interval of the Hindsville Formation.

An unconformity between the Pryor Creek Formation ("Moorefield Formation" of prior usage) and overlying Hindsville Formation was interpreted by Huffman (1958) who cited the apparent northward truncation of the Ordnance Plant Member by the Hindsville Formation in Mayes County and occurrence at one location of clasts of supposed Ordnance Plant Member incorporated into the basal Hindsville Formation. The existence of an unconformity was actually questioned by some of Huffman's own graduate students prior to 1958, including Douglass (1951) in Wagoner and Cherokee counties and Degraffenreid (1953) in Adair and Cherokee counties. Turmelle (1982), working primarily Adair County, also questioned the presence of an unconformity. In northern Arkansas no unconformity is interpreted between the type Moorefield Formation and overlying Batesville Sandstone/Hindsville Limestone (Garner, 1967; Handford, 1995).

During this investigation we observed little evidence of an unconformity between the Pryor Creek and Hindsville formations, or at least one of significant exposure and erosion. Apparent northward truncation by the Hindsville Formation will be addressed in a later section concerning the regional lithologic variation of the Ordnance Plant Member. In regards to the inclusion of Ordnance Plant clasts within the Hindsville Formation, we found no evidence of this. Based upon our observations, the contact between the Pryor Creek Formation and Hindsville Formation is considered conformable. Furthermore, comparison between conodont fauna of the two formations displays a close relationship, with no evidence of missing time at the scale provided by conodont biostratigraphic analysis.

Where the Pryor Creek Formation is absent, the Hindsville Formation rests unconformably on pre-Mayes strata of the Boone Group. It is not clear, however, if the Pryor Creek Formation was deposited then removed, or if these areas represented emergent areas during Pryor Creek deposition. We lean toward the latter scenario based on points that will be discussed in the portion of the following section concerning antecedent paleotopography. Thus the sub-Mayes unconformity is placed at the base of the Hindsville Formation where the Pryor Creek Formation is absent.

Distribution and Thickness

The distribution of the Pryor Creek Formation generally follows that described by Huffman (1958) for the "Moorefield Formation", excluding the Tahlequah Member, and is best exposed along the edge of the Mississippian outcrop belt in a line from northern Mayes County southward into Wagoner and Muskogee counties. Good exposures are also present in parts of Cherokee, Delaware, Adair, and Sequoyah counties. A gross thickness isopach map constructed from the integration of our measured sections and those of Slocum (1954), Huffman (1958), and Turmelle (1982) is illustrated in Figure 14.

In outcrop, the Pryor Creek Formation is thickest in the type area of central Mayes County, Oklahoma. At the proposed type locality, it is 60.5 feet (18.4 m) thick in the south high-wall section where both the upper and lower contacts are well exposed. In the north high-wall section, 49.6 feet (15.1 m) of the Pryor Creek Formation are exposed and include only the upper contact with the Hindsville Formation. At the Lindsey Bridge type locality, the Pryor Creek Formation is 95.8 feet (29.2 m) thick. From central Mayes County, the Pryor Creek Formation thins to the north, east, and south. In northern, southern, and eastern Mayes County, the Pryor Creek Formation averages 30 feet (9 m) and continues to thin northward and eastward and is absent in most of Craig County (see Vinita Quarry locality) and eastern Delaware County (Slocum, 1954). Southward, however, the Pryor Creek Formation thickens into Wagoner, Muskogee, and western Sequoyah counties.

In the southeastern part of the study area, the Pryor Creek Formation thins notably in parts of Cherokee, Adair, and central Sequoyah counties adjacent to, and across what we informally call the "Adair-Cherokee high" (Figure 12). Here, the Pryor Creek Formation ranges from 0 to 43 feet (0 to 13 m) thick. In areas where the Pryor Creek Formation is absent, the Hindsville Formation rests on pre-Mayes Group strata, as demonstrated at the Cookson locality (Figure 15). The Pryor Creek Formation is 11.9 feet (3.6 m) thick and overlain by the Hindsville

Formation at the Stilwell Quarry locality, which is representative of these strata in this area and is important because it highlights the difference between our interpreted placement of the Pryor Creek-Hindsville contact and that of previous workers (Routh, 1981; Turmelle, 1982). In fact, many of the adjacent sections include strata within the Pryor Creek Formation that are probably assignable to the Hindsville Formation.

Member Thickness and Distribution

Although the distribution and thickness trends of the individual members generally follow those of the formation as a whole, an important difference requires discussion. The Bayou Manard and Lindsey Bridge members display a greater thickness variability, especially within the type area, than does the Ordnance Plant Member. In fact, most of the thickness variation of the Pryor Creek Formation is accounted for within the lower two members. Both the Bayou Manard and Lindsey Bridge members are thickest at the Lindsey Bridge type locality where they are 44.8 feet (13.6 m) and 24.5 feet (7.5 m) thick, respectively. Both members thin in all directions away from the Lindsey Bridge type locality. But, after thinning briefly to the south and west, the Bayou Manard Member continues to thicken in both directions. The Lindsey Bridge Member, however, continues to thin and eventually "pinch-out" (Bollman, 1950). At the Ordnance Plant type locality, the Bayou Manard Member thins to 20 feet (6 m) thick and the Lindsey Bridge Member thins to 9.3 feet (2.8 m thick). In southern Mayes County and northern Wagoner County, the Bayou Manard Member averages 14 feet (4 m), whereas the Lindsey Bridge Member is as thin as 6 inches (15 cm). Farther south into Muskogee County, the Bayou Manard Member thickens and 34.7 feet (13.9 m) were measured at the Bayou Manard type locality, whereas no identifiable Lindsey Bridge Member lithology is present.

Overall thickness variation of the Ordnance Plant Member is less than that observed in the lower two members. The Ordnance Plant Member is 25.8 feet (7.9 m) thick at the Lindsey Bridge type locality, 26.5 feet (8.1 m) in the south high-wall section of the Pryor Creek type locality, and 27.5 feet (8.4 m) in the north high-wall section of the Pryor Creek type locality. In the shallow subsurface cores adjacent to the Pryor Creek type locality (Mayes cores M-206, M-209, and M-210), the Ordnance Plant Member averaged 26.4 feet (8.0 m) thick. In southern Mayes County and northeastern Wagoner County the Ordnance Plant Member is as much as 32 feet (10 m) thick. Reported thicknesses of the unit farther to the south range from 16 to 34 feet (5 to 10 m) (Huffman, 1958). Notable thinning of the Ordnance Plant Member occurs in northern Mayes County where it is 8 to 12 feet (2 to 3 m) thick in the vicinity of the Rock Creek locality and in the southeastern part of the study area where it is 4.3 feet (1.3 m) at the Stilwell Quarry locality. In both of these latter cases, thinning of the Ordnance Plant Member coincides with regional thinning of the Pryor Creek Formation adjacent to areas where it is absent and the overlying Hindsville Formation rests on pre-Mayes Group strata.

Thickening in the Subsurface to the West

From the edge of the outcrop belt, the Pryor Creek Formation thickens as it dips into the shallow subsurface of western Mayes County, as illustrated by the expanded sections in Mayes core M-207 and Mayes core M-211, where it is 126.6 feet (38.6 m) and 229.8 feet (70.0 m), respectively (Figures 12, 13, and 14). Thickening is, again, primarily within the Bayou Manard Member which is 83.3 feet (25.4 m) thick in Mayes core M-207 and 186.8 feet (56.9 m) in Mayes core M-211. Lindsey Bridge Member thins to 2.5 inches (6.4 cm) in Mayes core M-207 and is absent in Mayes core M-211. In Mayes cores M-207 and M-211, the Ordnance Plant Member is 43.1 feet (13.1 m) and 43 feet (13.1 m), respectively. Again, these thickness show the majority of thickening within the Pryor Creek Formation occurring within the Bayou Manard Member.

The Pryor Creek Formation rests unconformably on the Reeds Spring Formation in Mayes core M-207 and on Ordovician strata in core M-211. Farther to the southwest, the Pryor Creek Formation is 212.8 feet (64.9 m) thick and unconformably overlies the St. Joe Group above the Devonian Woodford Shale in the Baker Hughes BH-1 core (Okmulgee County, Oklahoma)

(Figure 16). In an unpublished report concerning the Baker Hughes BH-1 core, available at the Oklahoma Geological Survey core library, (OPIC), previous workers classified the upper 118 feet (36 m) of the Pryor Creek Formation as Meramecian “Moorefield Formation” and the lower 94.8 feet (28.9 m) as Osagean “Keokuk-Reeds Spring”.

Thickening associated with truncation of older Mississippian strata in the subsurface was interpreted by previous workers who considered the subsurface “Mayes” (Mississippian “black limestone”, Seminole “Mayes”, “Ada-Mayes”) to be correlative to the surface “Mayes” and lower Caney Shale (Aurin et al., 1921; Buchanan, 1927; Cline, 1934; Laudon, 1935; Barker, 1950; Huffman and Barker, 1950; Huffman, 1958; and Selk 1973). Others believed the subsurface “Mayes” to be down dip facies of Osagean strata (Cram, 1930; Brant, 1934, 1941a, 1941b; Selk, 1948; Harlton, 1956; Rowland, 1958; Jordan and Rowland, 1959; Ellzey, 1961; Furlow, 1964; Heinzelmann, 1964; Hoffman, 1964; Krueger, 1964; Harris, 1975) or Kinderhookian strata (Brant, 1957).

Although facies change within older Kinderhookian and Osagean strata is plausible due to the absence of typical St. Joe Group and Boone Group lithologies, such an interpretation requires an assumption that either the Woodford Shale was truncated by lower Mississippian strata (not observed anywhere at the surface) or that it also underwent significant facies change. When considered within the context of correlations between surface exposures (and shallow subsurface cores) in the type area of central Mayes County and the expanded sections in Mayes cores M-207 and M-211 and the Baker Hughes BH-1 core in Okmulgee County, a scenario of erosion and expansion to the west-southwest is simpler and more reasonable. Additionally, as will be discussed in the following section, the lithologic character of the expanded Pryor Creek Formation in Mayes cores M-207 and M-211, as well as in the Baker Hughes BH-1 core, is more comparable with that of surface exposures and shallow cores (Mayes cores M-206, M-208, M-209, and M-210) adjacent to the proposed Pryor Creek type locality than it is to known Kinderhookian-Osagean strata in northeastern Oklahoma.

Paleotopography

In outcrop, thicknesses of the individual members, and therefore the formation as whole, were strongly influenced by pre-depositional paleotopographic relief across the sub-Mayes unconformity surface. Clearly, paleotopography relief was greatest during deposition of the Bayou Manard and Lindsey Bridge members, which filled in much of the accommodation space, and was less of a factor during deposition of the Ordnance Plant Member. Small-scale relief along the unconformity surface influenced thickness within the lower part of the Bayou Manard Member (Figure 7B). Large-scale relief was described by previous workers as erosional chert “knobs” of the Boone Group (Dott, 1952; Degraffenreid, 1953; Huffman, 1958; Starke, 1961), that, in some instances, were reported to protrude up through the Mississippian and into the Pennsylvanian section. Large-scale paleotopographic relief was observed at the Ordnance Plant type locality where the Pryor Creek Formation drapes over highs at both the north and south ends of the section (Figure 17). Similar draping is present at the Lindsey Bridge type locality.

Regional scale paleotopography is represented best by the broad accommodation-based distribution of the Pryor Creek Formation, including the northward and eastward limits of the Pryor Creek Formation and the “Adair-Cherokee high” as shown. Thinning of the Pryor Creek Formation in southern Mayes and northern Wagoner counties is also a result of large-scale to regional-scale paleotopography. It also accounts for the thinning and thickening across the area from the Lindsey Bridge type locality, across the Ordnance Plant type locality, and into the shallow subsurface of southwestern Mayes County (Figure 13). In areas where the Hindsville Formation overlies pre-Mayes Group strata, it is conceivable that these were areas of emergent broad paleotopographic highs across which the Pryor Creek Formation was not deposited.

Although small-scale relief and perhaps some of the large-scale relief can be attributed to erosion along the sub-Pryor Creek unconformity, much of the large-scale and regional-scale relief is likely the result of a combination of erosion and pre-depositional tectonism. Buchanan (1927,

p. 1314) suggested a period of uplift and erosion following Osagean deposition and that the "… *Meramecian beds consequently had a very uneven, folded, faulted, and eroded platform upon which they might encroach. Elevation at the close of the Osagean in the Ozark area was accompanied by a general depression elsewhere in Oklahoma*". Wilhite et al. (2011) suggested that tectonism associated with the initial phases of the Ouachita Orogeny exerted periodic influence over depositional patterns during the Kinderhookian and Osagean. Similar tectonic influences on deposition and stratigraphic architecture have been discussed for Carboniferous strata in North America (Tankard, 1986). It is therefore reasonable to infer that results of tectonism played a role in the pre-Mayes Group depositional landscape and components within the Mississippian petroleum system (Harris, 1975).

Lithology and Character

The Pryor Creek Formation is broadly characterized by gray to dark brownish-gray, silty-shaly, fine-grained limestone, calcareous (and dolomitic) siltstone, fine to very coarse-grained limestone, and silty calcareous shale. This is a critical point in our proposed revisions because it distinguishes the Pryor Creek Formation from the type Moorefield Formation in northern Arkansas which consists predominantly of gray to black shale and ammonoid-bearing limestone concretions (Gordon, 1944; Ogren, 1968; Handford, 1995). In the southern portion of the outcrop area, in parts of Muskogee, Cherokee, and Adair counties, the Pryor Creek Formation become increasingly shaly; but, at that point it displays more similarity to the Ahloso Member of the Caney Shale 100 miles to the southwest, to which it is considered correlative and contiguous, than it does with the type Moorefield Formation 210 miles to the east (Barker, 1950; Elias, 1956).

Lithostratigraphic subdivisions within the Pryor Creek Formation, based on gross lithologic character differences, include the Bayou Manard, Lindsey Bridge, and Ordnance Plant members. Together these form a vertical lithologic succession that is generally consistent and recognizable throughout the outcrop area and into the shallow subsurface, regardless of overall thickness of the formation. Notable exceptions include areas where the Lindsey Bridge Member is absent and in the southernmost part of the outcrop area where it becomes difficult to differentiate between lithostratigraphic divisions within the Pryor Creek Formation with certainty.

Bayou Manard Member

In central Mayes County, the Bayou Manard Member is light brownish-gray, gray, brownish-gray, to dark gray, medium-bedded, shaly and silty lime mudstone-wackestone to dark gray to black silty calcareous mudrock with thin partings of dark brownish-gray-black calcareous shale that grades laterally to silty-shaly wackestone-packstone (Figure 18). Breaking the rock emits a strong petroliferous odor upon breaking. Scattered open marine fossils are common in the Bayou Manard Member, and include crinoids, brachiopods, bryozoan, ostracodes, trilobites, bivalves, gastropods, and occasional rugose corals. Resting and feeding traces are also common along some bedding planes. Although lime mudstone-wackestone beds are typically structureless interiorly, faint laminations and compacted *Planolites* burrows are not uncommon. Abundant glauconite, quartz silt, phosphate, and skeletal debris occur at the base of the Bayou Manard Member. Chert clasts derived from the underlying Boone Group occur locally at the base as well.

Previously described thinning of the Bayou Manard Member to the north, east, and south of central Mayes County coincides with an increase in relative abundance of microbioclastic (silt-sized indeterminate bioclasts) to very fine-grained bioclastic limestone lithologies. At the Rock Creek locality in northern Mayes County, the Bayou Manard Member is gray to medium bluish-gray very fine-grained bioclastic packstone-grainstone and lime mudstone-wackestone with white to pale yellow-gray chert nodules and disseminated glauconite (Figure 18). Similar lithologies are present in the shallow subsurface cores north of the Pryor Creek type locality (Figure 18E). In southern Mayes County near its border with Wagoner and Cherokee counties, the Bayou Manard Member is medium to dark bluish-gray, silty, lime mudstone-wackestone with lenses of microbioclastic (including silt-sized peloids) wackestone-packstone, and abundant *Zoophycos* burrows. At some locations, including the Big Hollow Recreation Area locality (Figure 18D), basal Bayou Manard Member beds are very thin to thin-bedded, platy, brownish-gray, shaly and silty lime mudstone-wackestone and microbioclastic wackestone-packstone, with silty calcareous shale partings, similar to that at the base of the unit in central Mayes County. Similar lithology was observed at the Stilwell Quarry locality and is characteristic of the member in the southeastern part of the outcrop area adjacent to the “Adair-Cherokee high” regional-scale paleotopographic feature.

Within its type section in Muskogee County, the Bayou Manard Member consists of three lithologic phases. The lower 4.3 feet (1.3 m) are thin to medium-bedded dark gray to black, dense to shaly, lime mudstone and hard calcareous shale. The middle phase is 15.1 feet (4.6 m) of thin to medium-bedded, dark brownish-gray to black, shaly-silty lime mudstone-wackestone with some silty-shaly microbioclastic wackestone-packstone and calcareous shale partings (Figure 18A). The exposed part of the upper phase is 15.5 feet (4.7 m) of thin to thick-bedded, light gray to medium gray, silty-shaly microbioclastic wackestone-packstone-(grainstone?) and calcareous shale partings. Both the middle and upper phases tend to weather platy to shaly. The lower phase is generally unfossiliferous, whereas the upper two phases contain abundant whole to partially abraded articulate and inarticulate brachiopods, similar to those observed in the Ahloso Member of the Caney Shale at the Hass ‘G’ Reference Locality along the Lawrence Uplift in Pontotoc County, Oklahoma (Elias, 1956; Huffman, 1958; Boardman and Puckette, 2006).

At the Lindsey Bridge locality, a 5.4 foot (1.6 m) interval dominated by dark gray to black, dense to shaly, lime mudstone-wackestone and platy shale is present 13 feet (4 m) above the base of the Bayou Manard Member and contains abundant nodules and discontinuous beds of black vitreous chert (Figure 19A). These chert nodules are similar to those observed in parts of the Reeds Spring Formation (Mazzullo et al., 2011) and appear to be associated with burrowing. At the Ordnance Plant type locality, black vitreous chert occurs in a single bed 4 feet (1 m) below the top of the unit. Black vitreous chert is also present 12.4 feet (3.8 m) above the base of the

Bayou Manard Member within the south high-wall section in the Pryor Quarry. At the Rock Creek locality, the Bayou Manard Member contains anastomosing light-colored chert. In the shallow subsurface cores of Mayes County, the Bayou Manard Member exhibits both light-colored and dark colored chert and is similar to parts of the underlying Reeds Spring Formation (Figure 19B). The similarities with the Reeds Spring Formation create the potential for misidentification in the subsurface; it has possibly attributed to some degree of the confusion surrounding past correlations. Chert is uncommon in the southern part of the outcrop area.

In the shallow subsurface of Mayes County (Mayes cores M-206 through M-211), the Bayou Manard Member is also characterized by interbedded gray to dark gray-black, lime mudstone-wackestone, silty-shaly microbioclastic wackestone-packstone, and calcareous shale with disseminated white-light gray fossil fragments and nodular light gray-blue to black chert, similar to that in the adjacent surface exposures. The base of the sections in these cores is also glauconitic and contains small grains phosphate. In Mayes core M-211, however, the Bayou Manard Member also consists of lithologies currently unknown from surface exposures. Some differences are diagenetic in nature, including increased chert (often in the form of pervasive matrix silicification of lime mudstone-wackestone and microbioclastic wackestone-packstone) and abundant dolomite associated with silicification (from isolated rhombs to pervasive recrystallization). Other differences are depositional, specifically the presence spiculitic wackestone-packstone-grainstone, often overprinted by diagenetic chert facies.

Lindsey Bridge Member

The defining characteristic of the Lindsey Bridge Member is the occurrence of cross-stratified, fine to very coarse bioclastic packstone-grainstone. Allochems include abraded open marine fauna (crinoids, bryozoans, bivalves, ostracodes, brachiopods), ooids, peloids, and assorted lithoclasts (most commonly sand to gravel-sized chert). Bioclasts may be micrite-coated. Where the unit is thickest in central Mayes County, however, it displays greater lithologic diversity and can be divided into three lithologic phases (Figures 9A and 20). At the Lindsey Bridge type locality, the lower phase is a 6 to 18 inch (15 to 45 cm) bed composed of medium to very coarse skeletal packstone-grainstone with abundant whole to partially abraded brachiopods and internal cross-stratification (Figure 20). In the south high-wall section at the Pryor Creek type locality, the lower phase packstone-grainstone is as much as 6 feet (2 m) thick and becomes a very coarse poorly sorted wackestone-packstone to floatstone-rudstone. The middle phase at both locations grades vertically from gray to dark gray, shaly-silty, lime mudstone-wackestone into light brownish-gray to brownish-gray, shaly-silty, burrowed, microbioclastic wackestone-packstone. Bedding in the middle phases is thin to medium. Internal laminations are rare to common, depending on the amount of bioturbation, which is often fabric-destructive. Abundant large *Planolites* are present at the transition between middle and upper phases at the Lindsey Bridge type locality. The upper phase is well developed at the Lindsey Bridge type locality. At the Pryor Creek type locality, the upper phase is present within the north high-wall section, but is absent in the south high-wall section. The upper phase consists of cross-stratified, thin to thick-bedded, fine to very coarse bioclastic grainstone with angular to subrounded chert clasts ranging in size from coarse sand to cobble.

Where the unit thins away from central Mayes County, the Lindsey Bridge Member loses most or all of the shaly-silty limestone and calcareous shale, and is dominated by typical fine to coarse bioclastic packstone-grainstone lithologies. At the Ordnance Plant type locality, the Lindsey Bridge Member consists of, in ascending order, 6 feet (2 m) thick interval of fine to coarse bioclastic and lithoclastic packstone-grainstone (the entire Lindsey Bridge Member as defined by Huffman, 1958), 20 inches (60 cm) of dark gray silty calcareous shale, and 14 inches (36 cm) of fine to coarse bioclastic packstone-grainstone.

At the Lindsey Bridge type locality and within the south high-wall section at the Pryor Creek type locality, the unit displays large-scale cross-bedding (Figure 13B). Swinchatt (1967) interpreted the cross-stratification as a series of stacked prograding foresets, excluding the basal grainstone. Interestingly, the direction of progradation is to the northeast, apparently away from the paleotopographic high associated with the Ordnance Plant type locality as shown in Figure 13. Paleotopographic highs along the carbonate platform may have provided barriers across which shoreward prograding foresets developed in a similar manner to those described for rimmed platforms (Handford and Loucks, 1993).

Ordnance Plant Member

Within the type area of central Mayes County, three lithologic phases are present in the Ordnance Plant Member, although not always completely exposed (Huffman, 1958). The lower phase is predominantly dark brownish-gray, shaly calcareous siltstone, containing horizontal to cross-laminations and horizontal burrows (Figures 10C and 21A). The middle phase of the Ordnance Plant Member is thin to thick-bedded, calcareous and partially dolomitic siltstone to very fine-grained sandstone (see Figures 6, 7C and 21B). Common in the middle phase are internal cross-laminations, symmetrical ripples along the bedding surfaces, and horizontal and vertical burrows. Thin zones of shell accumulation occur within the massive siltstone as well. The upper phase is greenish-gray dark brownish-gray silty calcareous shale and thin-bedded silty-sandy fine to coarse-grained bioclastic wackestone-packstone-grainstone (Figures 7C, 10B, and 21C). Carbonate allochems throughout the Ordnance Plant Member are dominated by silt-sized peloids and indeterminate skeletal fragments (microbioclasts). Scattered recognizable skeletal debris is present and includes ostracodes, crinoids, brachiopods, and bryozoans. To the north the upper and lower phases thin, with the upper phase eventually absent at the Strang Bridge locality. To the south the middle siltstone phase grades into thin-bedded, very silty, microbioclastic wackestone-packstone-grainstone in southern Mayes County before becoming progressively dominated by dark gray to brownish-black, mildly calcareous mudrock/shale and greenish-gray to brownish-gray silty calcareous shale/shaly siltstone farther to the south and southeast, as demonstrated by the section at the Bidding Creek locality (Figure 21C). The southward transition was attributed by Huffman (1958) to thinning of the middle siltstone phase. The northward thinning and loss of the upper phase, however, he attributed to erosional truncation below the Hindsville Formation; an interpretation he supported by the observed apparent juxtaposition of the Hindsville Formation on increasingly older phases of the Ordnance Plant Member northward. Although this is feasible, an alternative hypothesis is that no unconformity exists between the two, or at least not one that displays significant removal of underlying strata, and the northward trend is simply a result of the continuation of the dip-oriented facies change and depositional thinning described to the south.

In both Mayes core M-207 and Mayes core M-211, as well as in the Baker Hughes BH-1 core, the Ordnance Plant Member is lithologically consistent with exposures in that it is consists of silty-shaly, very fine-grained limestone, shaly calcareous siltstone, and dark gray-black calcareous shale.

Intra-Formational Stratigraphic Boundaries and Surfaces

Bayou Manard-Lindsey Bridge Contact

The contact between the Bayou Manard and Lindsey Bridge Members is placed at the base of the first coarse bioclastic packstone-grainstone above the lime mudstone-wackestone of the Bayou Manard Member, marking the transition from low-energy deposition to high-energy deposition (Figure 22A). The contact is sharp and flat to irregular. Evidence of erosion along the surface includes truncation of upper Bayou Manard Member beds and rip-up clasts within the basal Lindsey Bridge Member. Within several surface exposures the top of the Bayou Manard Member contains unlined borings that have been passively filled with medium to coarse bioclastic grainstone identical to that of the overlying basal bed of the Lindsey Bridge Member. The contact is interpreted as a marine firm-ground discontinuity formed during a depositional hiatus (Hillgartner, 1998; Schwarz and Buatois, 2012).

Lindsey Bridge-Ordnance Plant Contact

The contact between the Lindsey Bridge and Ordnance Plant Members is an unconformity of at least local to sub-regional extent. Snider (1915) and Huffman (1958) recognized no such unconformity. Swinchatt (1967) interpreted an unconformity between the Lindsey Bridge and Ordnance Plant members following observation of apparent truncation of dipping foreset beds of the Lindsey Bridge Member by the Ordnance Plant Member at the Lindsey Bridge type locality. In the south high-wall section at Pryor Creek type locality, dipping beds of the Lindsey Bridge Member again appear to be truncated by the Ordnance Plant Member. In the north high-wall section the contact is an irregular and possibly scalloped surface with phosphate mineralization at the top of the Lindsey Bridge Member and clasts of Lindsey Bridge grainstone incorporated into the overlying shaly calcareous siltstone at the base of the Ordnance Plant Member (Figure 22A). A similar relationship was observed in the Mayes cores M-206 and M-210 (Figure 22E). At the Ordnance Plant type locality, the contact between the Lindsey Bridge and Ordnance Plant members was adjusted upward to a position at the top of the second coarse bioclastic packstone-grainstone bed previously placed within the Ordnance Plant Member (Huffman, 1958). The top of this limestone bed is locally irregular and partially mineralized. Above this bed, the Ordnance Plant Member contains pebble to cobble-sized chert clasts, as well as cobble-sized pieces derived from the Bentonville Formation and Short Creek Oolite Member. At the Stilwell Quarry locality, the contact between the two members is placed at an irregular surface at the top of the interpreted Lindsey Bridge Member, above which is an increase in the number of chert clasts and shaly calcareous siltstone interpreted as Ordnance Plant Member (Figure 22D). This is a deviation from the interpretation of previous workers who, in this section as well as other sections nearby, extended the entire Pryor Creek Formation farther upward into what we consider to be clearly Hindsville Formation (Huffman, 1958; Huffman et al., 1966;

Routh, 1981; Turmelle, 1982). No unconformity is currently recognized in Mayes core M-207, Mayes core M-211, and the Baker Hughes BH-1 core.

Within the south high-wall section at the Pryor Creek type locality, the lower part of the Ordnance Plant Member contains moderate glauconite and phosphate grains within a dark gray shaly-silty lime mudstone-wackestone 1.5 to 2.5 feet (0.5 to 0.8 m) above the unconformity, similar to that observed here at the base of the Bayou Manard Member. This is significant because, as previously discussed, Heinzelmann (1964) reported two glauconite zones in the subsurface. The first was placed at the base of his Osagean “St. Joe Group” and is associated with black shale and no silt, whereas the second glauconite was placed within the brown silty shale/shaly siltstone at the base of his “Moorefield formation”. The former could be the true base of the Pryor Creek Formation (base of the Bayou Manard Member), and the latter the base of the Ordnance Plant Member.

Conodont Biostratigraphy

Snider (1915) considered all of the “Mayes” to be Chesterian in age. Huffman (1958) considered the entirety of his “Moorefield Formation” to be Meramecian in age, based on correlations with the type Moorefield Formation and Ruddell Shale of northern Arkanss, which Gordon (1944) considered equivalent to the St. Louis and Ste. Genevieve, respectively, of the Upper Mississippi Valley. Ormiston (1966) reported a Chesterian age for the Bayou Manard Member. Selk (1973) and Brenckle et al. (1974) interpreted the Bayou Manard Member to be equivalent to the St. Louis Limestone.

Our conodont recoveries suggest that the Bayou Manard Member falls within the *Apatognathus scalensus-Cavusgnathus* Zone (upper St. Louis-equivalent) (see Figure 3). Within the study area of this report, rocks equivalent to the lower St. Louis Limestone were only observed at the Vinita Quarry locality below the Hindsville Formation. Lower St. Louis-equivalent strata are present farther to the northeast, in Ottawa County, Oklahoma, where they unconformably overlie the Ritchey Formation. Conodont fauna recovered from the Lindsey Bridge and Ordnance Plant Members are characteristic of *Gnathodus bilineatus-Cavusgnathus charactus* Zone of Collinson et al. (1971), and thus these units are no older than earliest Chesterian and equivalent to the Ste. Genevieve Limestone. It should be noted that the Meramec-Chester contact has been variously placed at either the base or top of the Ste. Genevieve Limestone or its equivalent (Gordon, 1944; Branson, 1959; Ross and Ross, 1985; Maples and Waters, 1987; Boyd, 2008; Koch et al., 2014). We herein follow Maples and Waters (1987) and considered the Meramec-Chester boundary to coincide with contact between the St. Louis Limestone and Ste. Genevieve Limestone. Although this point may seem trivial, the common application of terms such as "Ste. Genevieve" within the southern Mid-Continent, the informal use of chronostratigraphic divisions (Osage, Meramec, Chester) in the subsurface, and the possible presence of multiple key stratigraphic boundaries makes accurate age assignments more critical in terms of regional correlation and construction of an accurate stratigraphic framework within the subsurface.

Regional Correlations

Conodont recoveries from the Pryor Creek Formation support its correlation with at least the Ahloso Member of the Caney Shale in southern Oklahoma (Elias, 1956; Haywa-Branch, 1988; Boardman and Puckette, 2006) and the lower Barnett Shale of Texas (Hass, 1953; Boardman and Puckette, 2006; Singh, 2007)

All conodont recoveries used for this report were from surface exposures. The slim-hole nature of the Mayes County cores and the Baker Hughes BH-1 core precluded collection of sufficient bulk samples for biostratigraphic processing and evaluation. Selk and Ciriacks (1968) and Selk (1973), referencing the Amoco collections, reported the recovery of Meramecian conodonts from subsurface cores in north-central Oklahoma. This included instances without representative Osagean forms between those identified as Meramecian and Kinderhookian, although no specific details were given, nor were specimens illustrated. Therefore, without properly documented conodont recoveries from the subsurface, we considered clear biostratigraphically-constrained correlation of the Pryor Creek Formation with the subsurface "Mayes" unresolved. Such correlations are hindered by very low conodont yields (number of identifiable specimen per kilogram of rock) from the subsurface "Mayes" or Mississippian "black limestone" sampled from cores; a problem exacerbated by the limited volume of material available to process when working with core. A similar poor recovery is typical of the Bayou Manard Member of the Pryor Creek Formation at the surface; but, here the problem may be alleviated through the availability of larger bulk sample sizes.

SUMMARY AND DISCUSSION

The introduction of a new term, Pryor Creek Formation, reduces confusion because draws a clear distinction between it and the Moorefield Formation of northern Arkansas and more aptly reflects the lithologic nature of the lower Mayes Group interval in Oklahoma. Moreover, the position of the type area of the Pryor Creek Formation along the western edge of the Mississippian outcrop belt provides a more relevant point of reference for geologists concerned with petroleum plays in time-equivalent strata and subjacent strata affected by the sub-Mayes unconformity in the subsurface of Oklahoma.

The proposed lithostratigraphic revisions, however, go beyond a simple name change. Integration of conodont biostratigraphic data and observations made in the light of modern stratigraphic concepts instills within these revisions a temporal and genetic significance, resulting in a comprehensive stratigraphic framework (Figure 23) within a more favorable geographic position for comparison with the subsurface in Oklahoma. The conodont biostratigraphic data place both the Tahlequah Limestone and the Pryor Creek Formation in a regional to global context through time-constrained correlations and support the removal of the Tahlequah Limestone from the Mayes Group. Conodont data and field observations clearly demonstrate a significant unconformable separation between the Tahlequah Member and overlying Bayou Manard Member. This gap in time spans an interval representative of at least the lower St. Louis-equivalent portion of the Meramecian; an interval which is recorded in strata present in the Tri-State Mining District based on the co-occurrence of *Taphrognathus* and *Cavusgnathus*, a characteristic of lower St. Louis-equivalent strata (uppermost *Taphrognathus varians-Apatognathus* Zone). In contrast, the Tahlequah Limestone yielded *Taphrognathus varians* and the Bayou Manard Member has yielded species of C*avusgnathus*; but, neither unit yielded both. Conodont recoveries from the Tahlequah principal reference section also establish a correlation between the Tahlequah Limestone and Ritchey Formation (Boone Group) of Boardman et al. (2013). Furthermore, conodont fauna from the Tahlequah principal reference locality, in such close proximity to the original type section, prove that the Tahlequah Limestone is not St. Louis-equivalent as suggested by previous workers (Selk, 1973; Brenckle et al., 1974; and Routh, 1981), thus casting some doubt as to the validity of past correlations.

The Pryor Creek Formation, consisting of the three remaining members, is therefore a more genetically cohesive depositional package (depositional sequence) that is bounded below by a regionally-significant, sequence bounding unconformity and above by an unconformity-correlative conformity surface (sequence boundary) separating the Pryor Creek Formation from Hindsville Formation. Internally the Pryor Creek Formation consists of stratigraphic boundaries and surfaces that suggest a more complex depositional history than the simple transgressive-regressive model suggested by Huffman (1958). Deposition of the Pryor Creek Formation was clearly influenced by pre-Mayes paleotopography, more so during deposition of the lower two members. The diminishing influence of regional paleotopography on thickness of individual members suggests that deposition of the Pryor Creek Formation occurred as filling of increased accommodation space following the sub-Pryor Creek unconformity, a model that is similar to that for the Moorefield Formation in Arkansas proposed by Handford (1995). The lithologic succession demonstrates an overall shallowing upward, the transgressive-regressive cycle of

Huffman (1958). Lithologic variation within the Pryor Creek Formation and identification of key intraformational surfaces (member contacts) highlight the potential for higher-order depositional cyclicity. This report represents the initial stages of redefining the stratigraphic framework for this interval at the surface and highlights potential key elements within the subsurface petroleum system.

AKNOWLEDGEMENTS

We thank Kemp Quarries and BuzziUnicem, U.S.A. for granting access to their quarries over the course of this investigation. We also thank the people at the Oklahoma Geological Survey OPIC for their assistance with the core and related material. We also acknowledge the members of the Mississippian Consortium at Oklahoma State University for funding and support. Godwin and Puckette would also like to acknowledge the significant contributions of Dr. Darwin R. Boardman II, who passed away in January of 2015, in not only this study, but many others. We miss his enthusiasm for field-based scientific study and breadth of knowledge of various topics in geology. We even miss his cell phone ringing to the tune of "Boomer Sooner" during the middle of a school day on the campus of Oklahoma State University.

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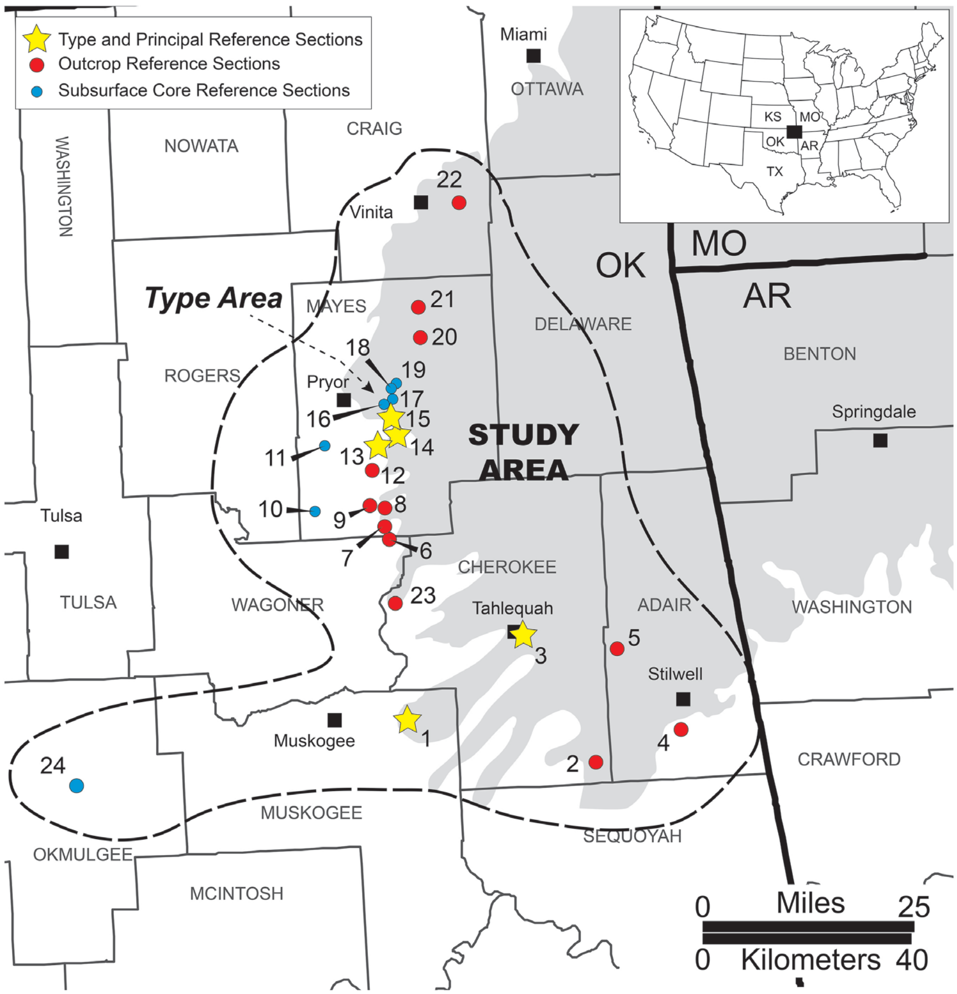
FIGURES



1) Bayou Manard type locality
2) Cookson locality
3) Tahlequah principal reference locality
4) Stilwell Quarry locality
5) Bidding Creek locality
6) Big Hollow Recreation Area locality
7) Earbob Recreation Area locality
8) Cedar Crest Lake locality
9) Spring Creek Recreation Area locality
10) Mayes core M-211
11) Mayes core M-207
12) Chouteau Bend locality
13) Ordnance Plant type locality
14) Lindsey Bridge type locality
15) Pryor Creek type locality (Pryor Quarry)
16) Mayes core M-209
17) Mayes core M-210
18) Mayes core M-206
19) Mayes core M-208
20) Strang Bridge locality
21) Rock Creek locality
22) Vinita Quarry locality
23) Hulbert locality
24) Baker Hughes BH-1 core

Figure 1. Study area map with locations of measured sections discussed in the text.

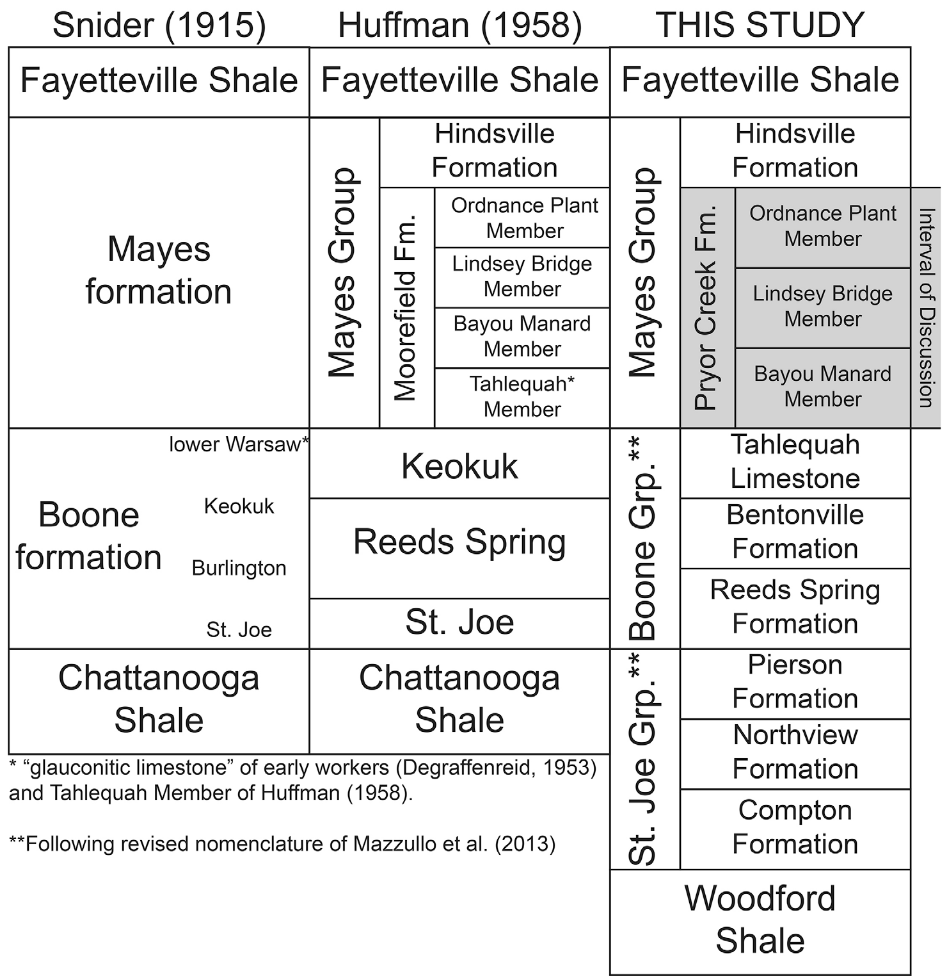


Figure 2. Pertinent historical development of the lithostratigraphic nomenclature of the lower Mayes Group, including the revised nomenclature of this study.

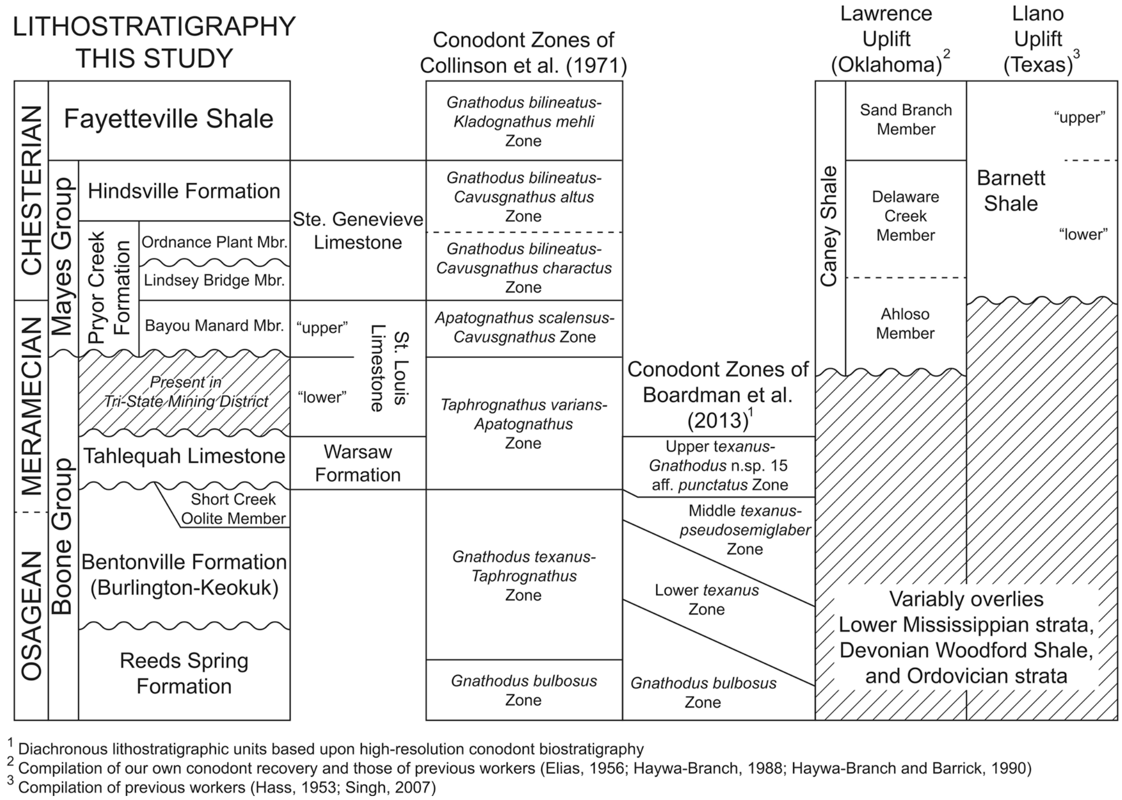


Figure 3. Revised lithostratigraphy in terms of conodont biostratigraphy and time-equivalent correlations with the Caney Shale and Barnett Shale.

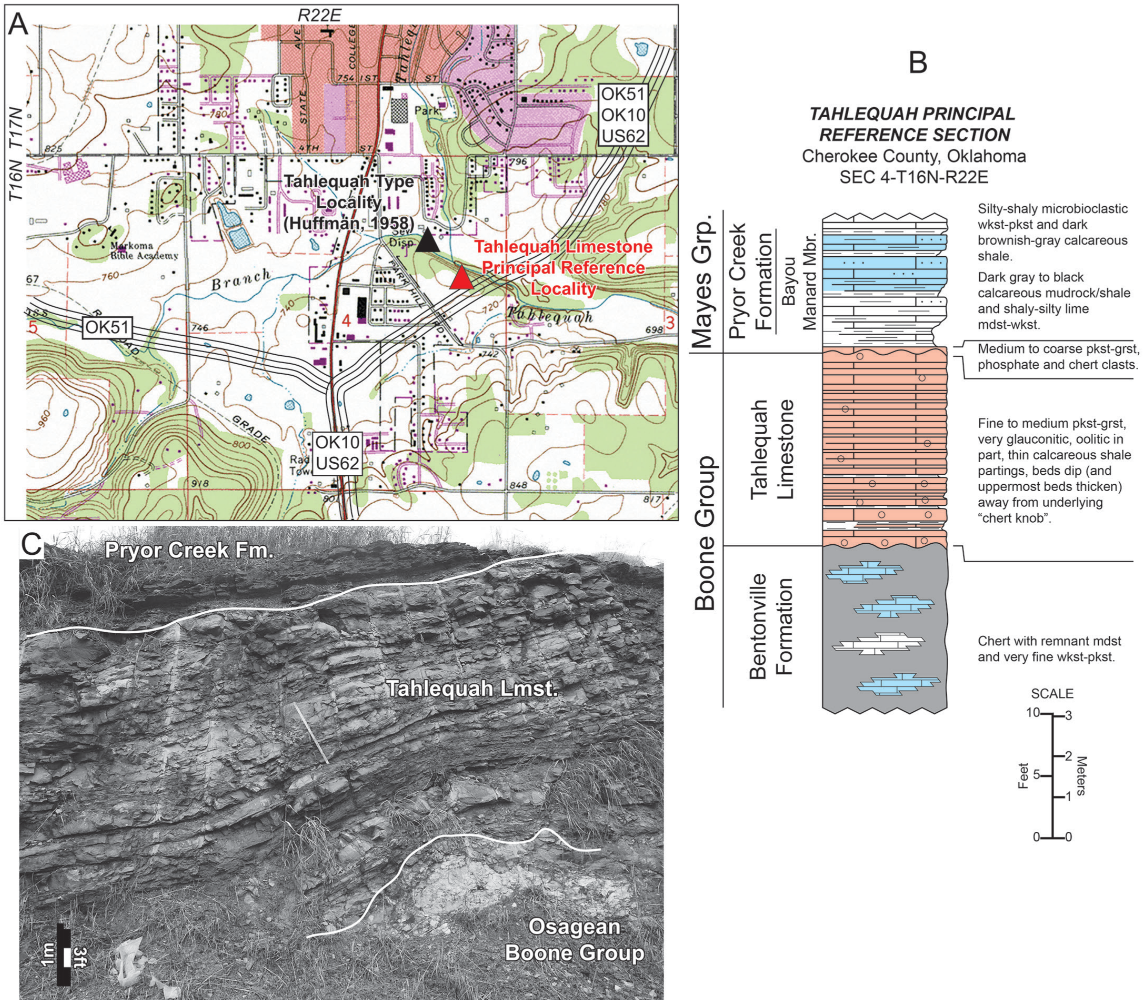


Figure 4. Tahlequah principal reference locality. (A) Location topographic map showing the Tahlequah Principal Reference Locality (red triangle) and original type locality (black triangle). (B) Measured stratigraphic section (key is shown in Figure 6). (C) Outcrop photograph of the Tahlequah Principal Reference Section with upper and lower unconformable contacts.

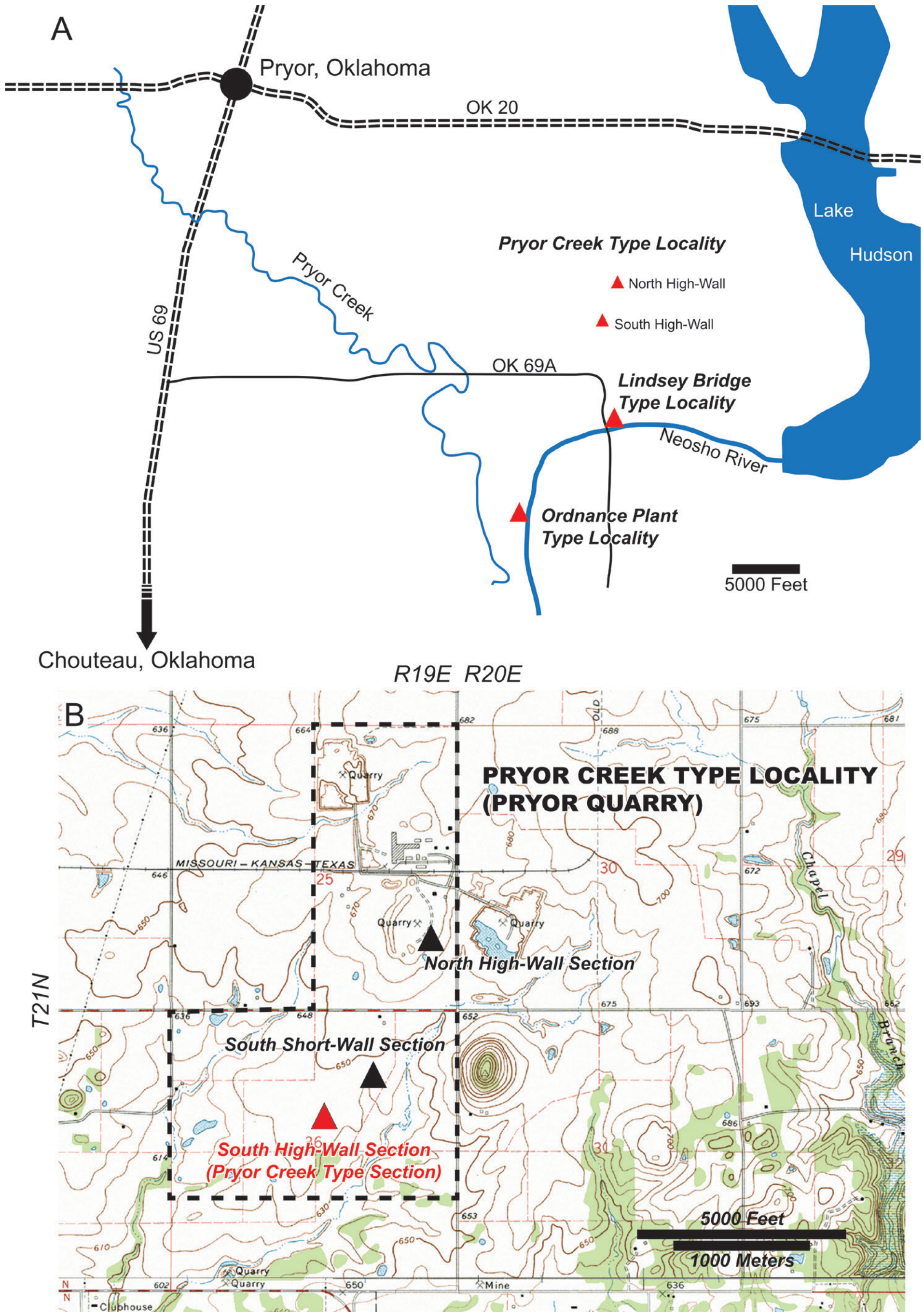


Figure 5. Pryor Creek type locality. (A) General location map showing the location of the proposed Pryor Creek type locality and reference sections at the Ordnance Plant and Lindsey Bridge type localities. (B) Location topographic map showing the Pryor Creek type locality with the south high-wall section (red triangle), south short-wall (Hindsville) section, and north high-wall section.

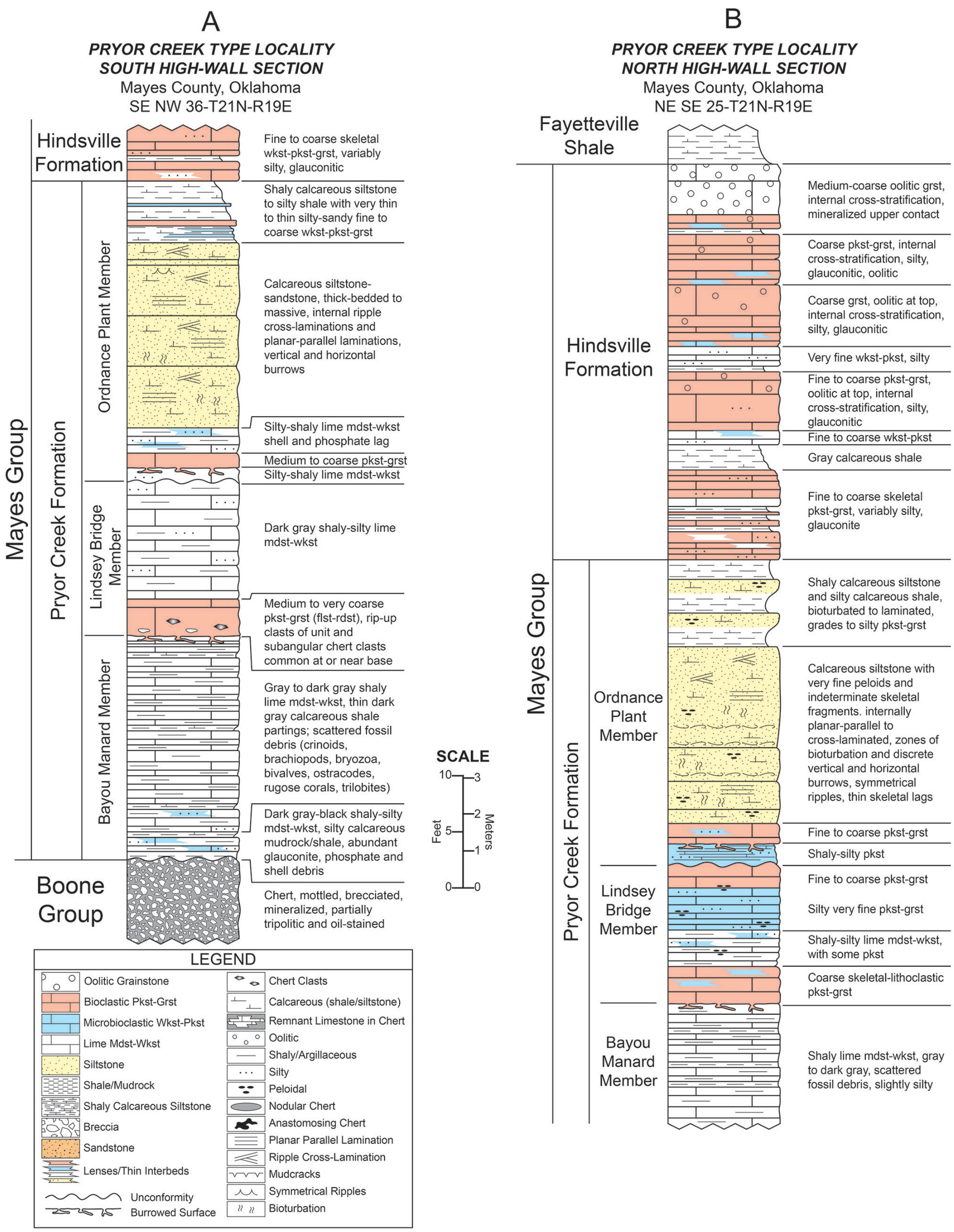


Figure 6. Pryor Creek Formation type locality. (A) South high-wall measured section. (B) North high-wall measured section.

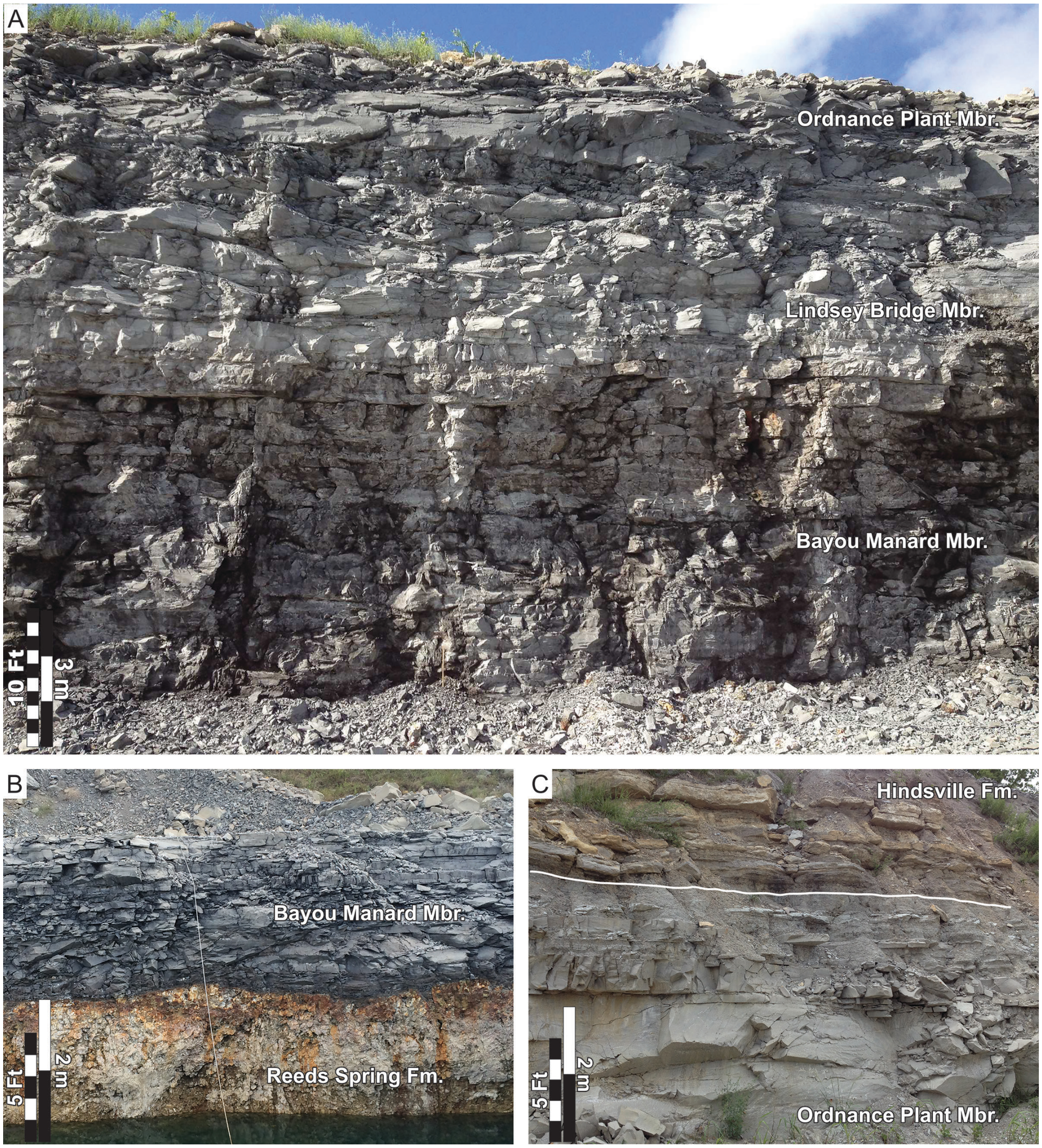


Figure 7. Pryor Creek type locality outcrop photographs from the south high-wall section. (A) Main portion of the south high-wall section. (B) Contact between the Bayou Manard Member and the Boone Group (Pineville Tripolite facies of the Reeds Spring Formation). (C) Contact between Ordnance Plant Member and Hindsville Formation.

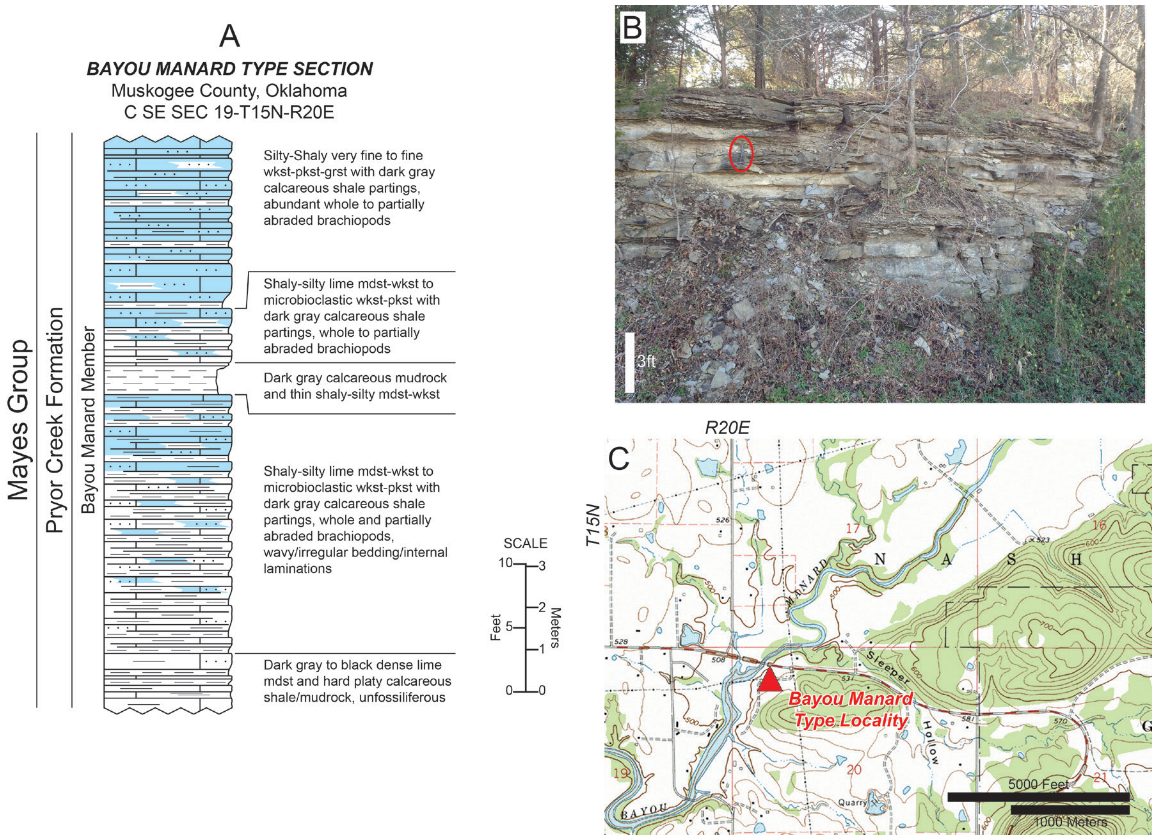


Figure 8. Bayou Manard type locality, Muskogee County, Oklahoma. (A) Measured stratigraphic section. (B) Outcrop photograph (12-inch rock hammer for scale). (C) Location topographic map.

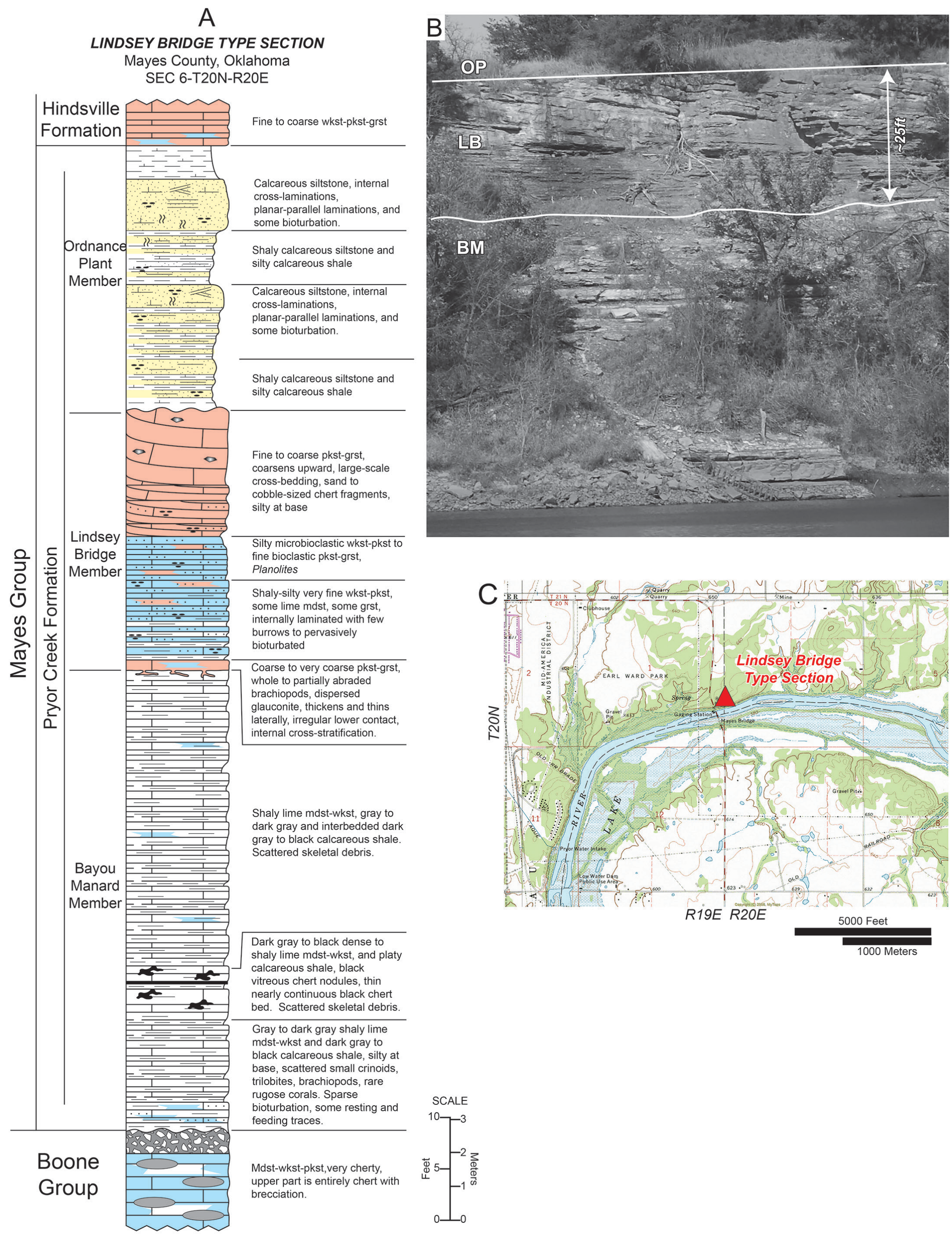


Figure 9. Lindsey Bridge type locality. (A) Measured stratigraphic section. (B) Outcrop photograph, Lindsey Bridge Member is approximately 25 feet thick, but thickens and thins laterally. Also, note large-scale cross-bedding in Lindsey Bridge Member. (C) Location map showing Lindsey Bridge type locality.

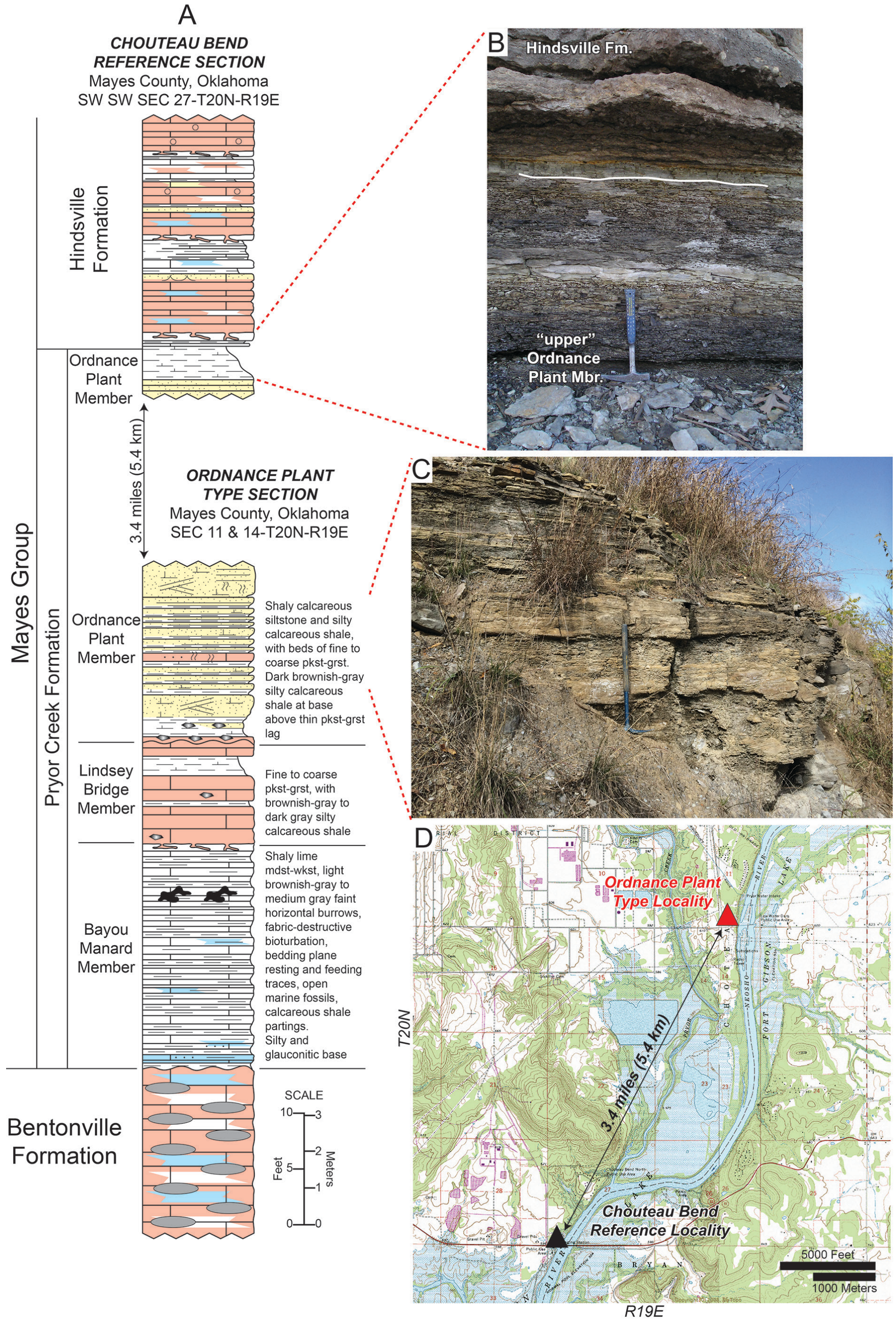


Figure 10. Ordnance Plant composite type section. (A) Measured stratigraphic sections from the Ordnance Plant type locality (lower) and the Chouteau Bend locality (upper). (B) Outcrop photograph of Ordnance Plant-Hindsville contact at the Chouteau Bend section. (C) Outcrop photograph of the lower to middle Ordnance Plant Member at the Ordnance Plant type locality, paleo pick is 36 inches long. (D) Location topographic map showing positions of the Ordnance Plant type locality (red triangle) and Chouteau Bend locality (black triangle).

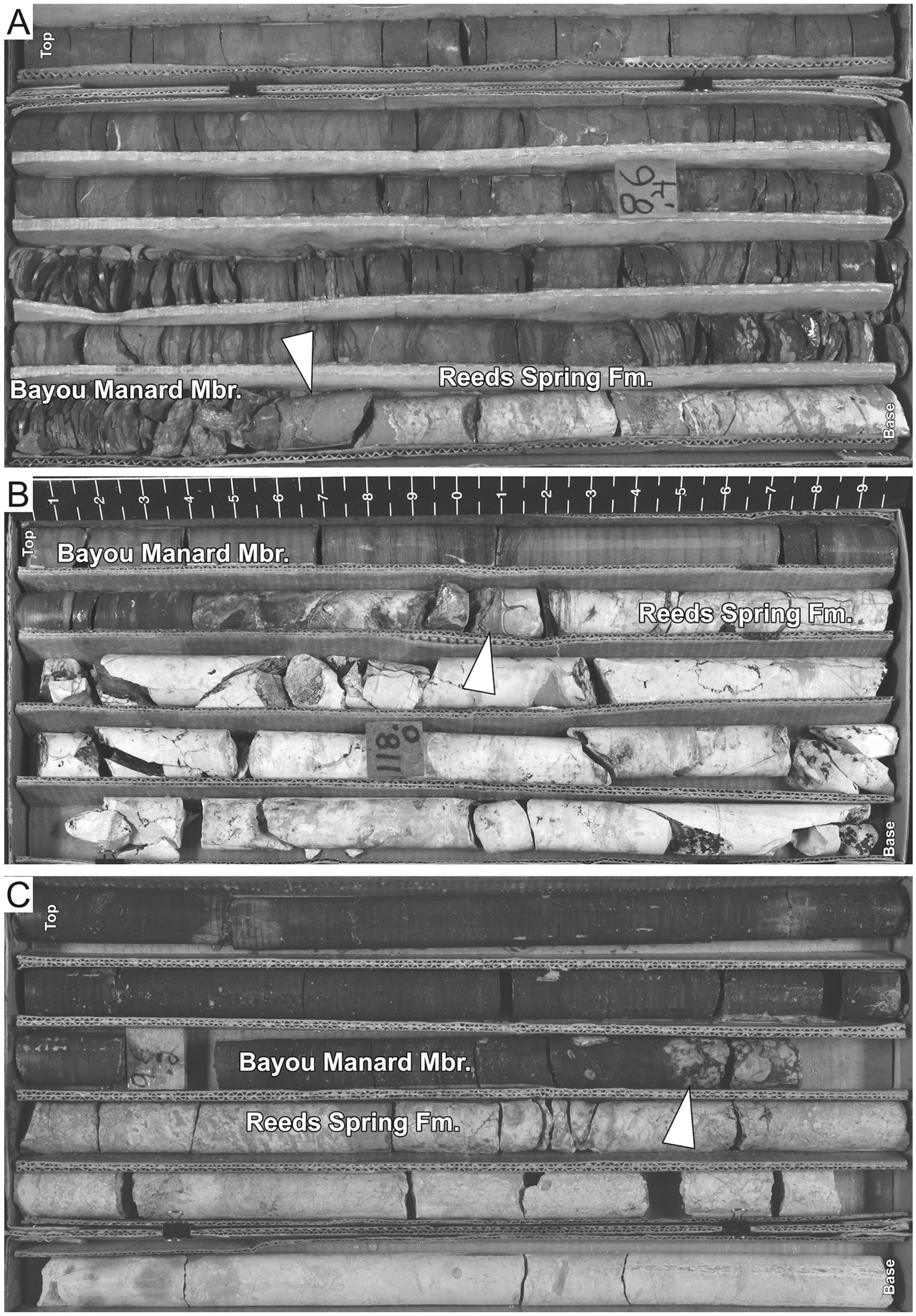


Figure 11. Sub-Mayes unconformity photographs from Mayes County shallow subsurface cores (A) M-208 (core depths: 89.7 to 80.4 feet), (B) M-206 (core depths: 120.2 to 111.4 feet), and (C) M-209 (core depths: 103.6 to 92.0 feet). Core box length is 2 feet. White arrows indicate contact between the Bayou Manard Member of the Pryor Creek Formation and the underlying Reeds Spring Formation, including oil-stained altered Reeds Spring (Pineville Tripolite) in (B) and (C).

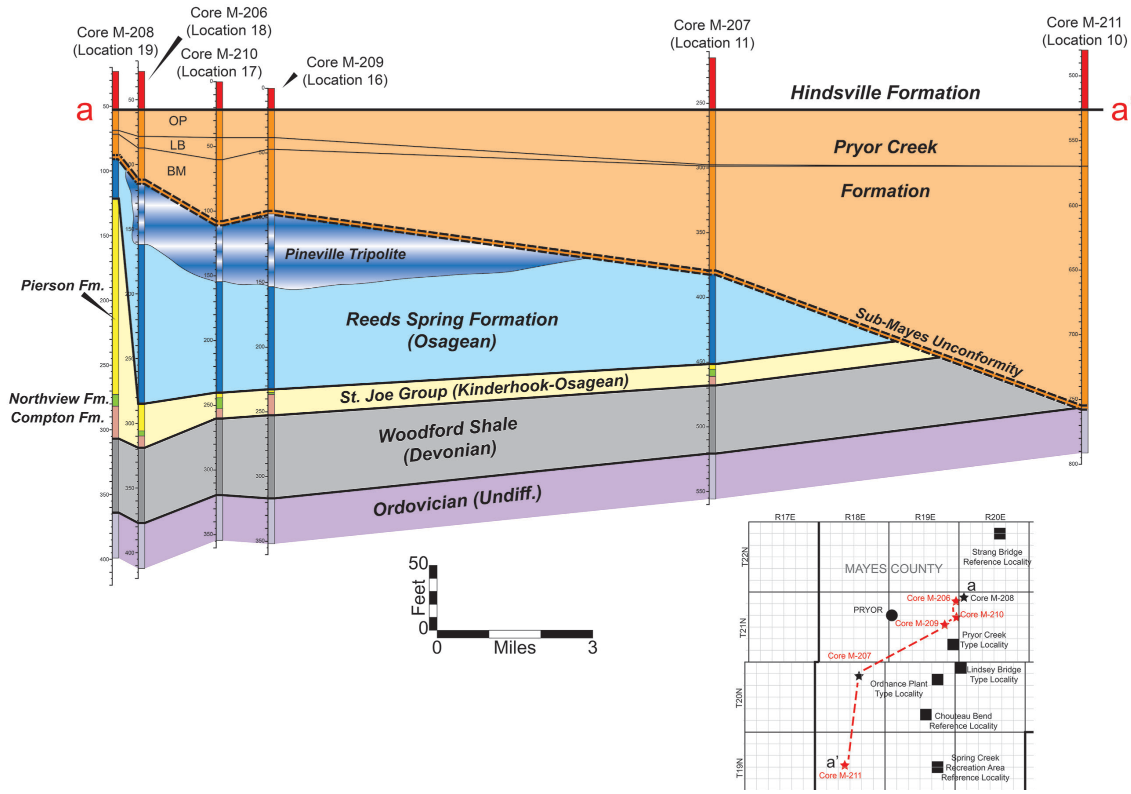


Figure 12. Cross-section a-a’ extending from Mayes cores located just north of the Pryor Creek type locality (left) southwest into subsurface of southwestern Mayes County (right).

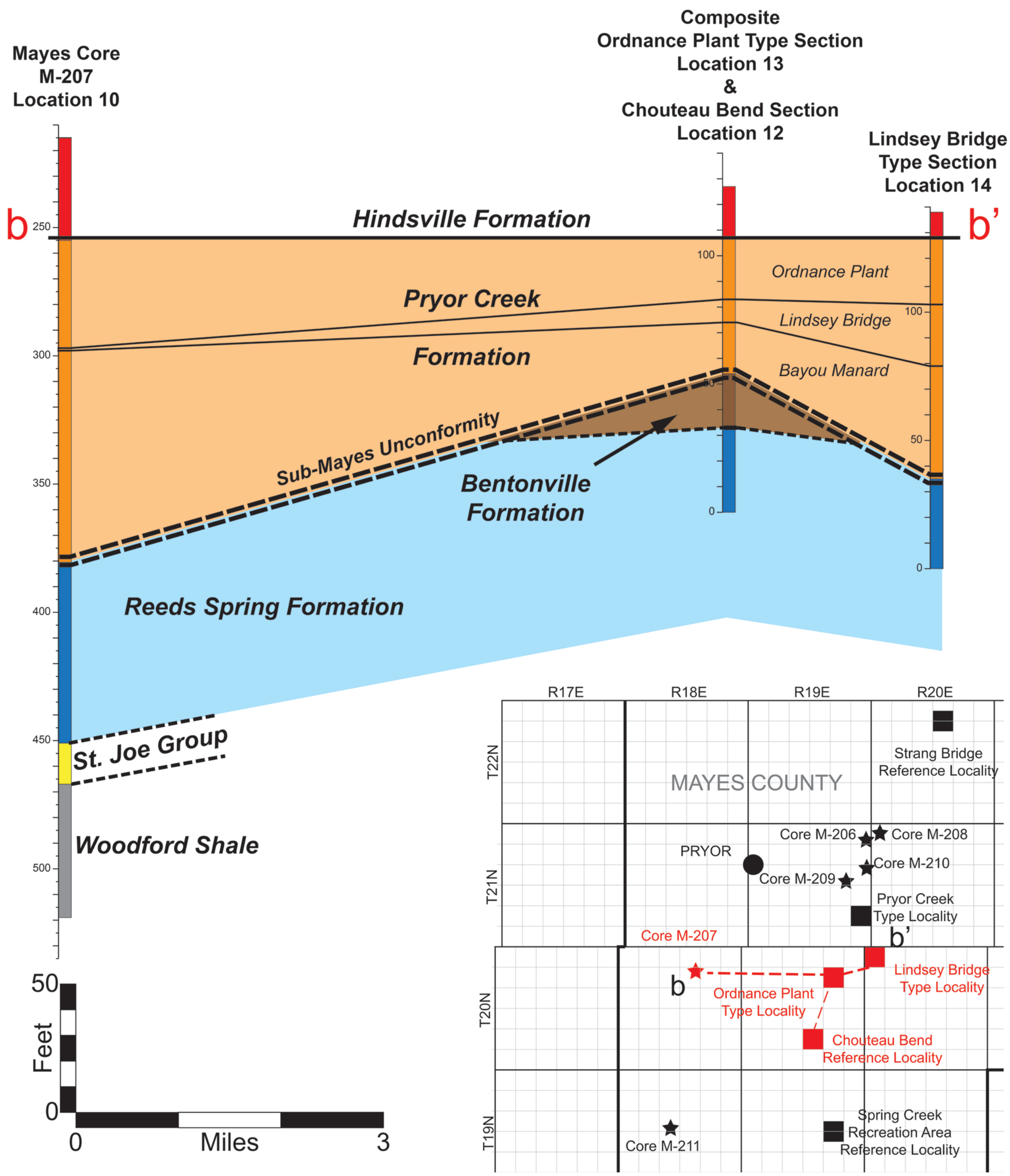


Figure 13. Cross-section b-b' from the Lindsey Bridge type locality across the composite Ordnance Plant type section (Ordnance Plant type section and Chouteau Bend reference section) to the Mayes core M-207 illustrating stratigraphic relationship between Pryor Creek Formation and older Mississippian strata below the sub-Mayes unconformity. The figure also illustrates the relationship between paleotopographic relief and thickness of the Pryor Creek Formation.

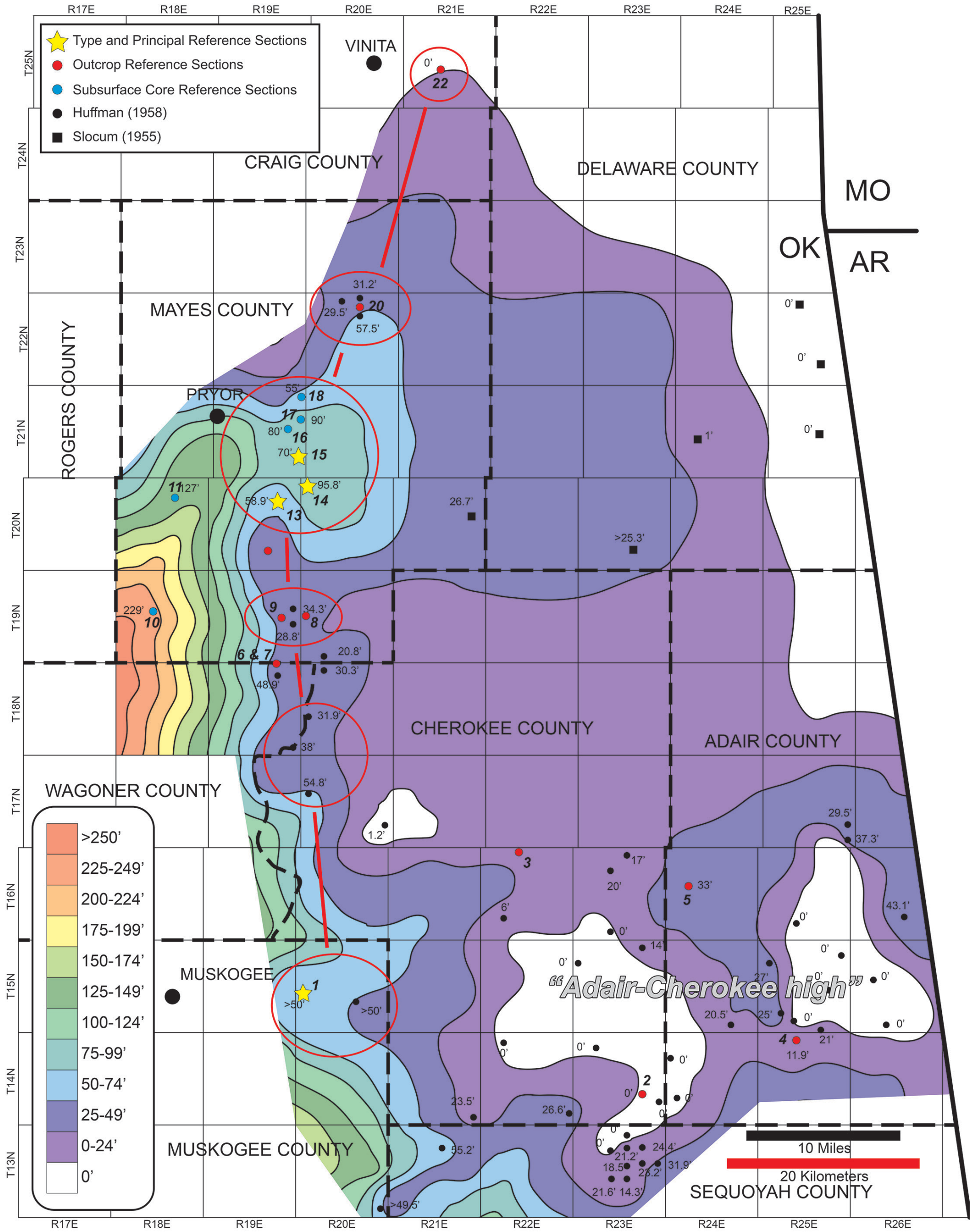


Figure 14. Pryor Creek Formation gross thickness map based on the compilation of observations original to this report (red circles, blue circles, and yellow stars) with those of Slocum (1954; black squares) and Huffman (1958; black circles). The edge of the Pryor Creek Formation to the north and east, as well as adjacent to the "Adair-Cherokee high" is delimited by the occurrence of the Hindsville Formation resting on pre-Mayes Group strata (typically Boone Group) as is shown in Figure 15. Contour interval is 25 feet (7.6 m). Location numbers are provided (bold italic) for sections examined in this study. Line of cross-section, shown in red, is for Figure 23.

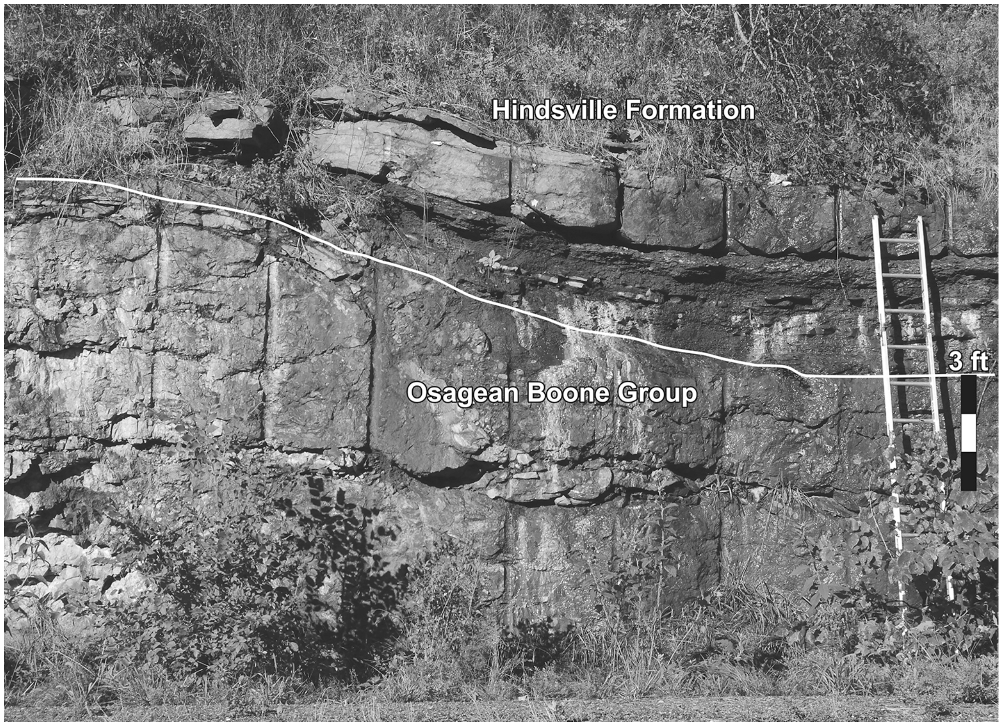


Figure 15. Cookson locality outcrop photograph showing the Hindsville Formation on top of very cherty limestone of the Boone Group. The lower dark gray to black shale interval of the Hindsville Formation thins across the erosional relief of the Boone Group.

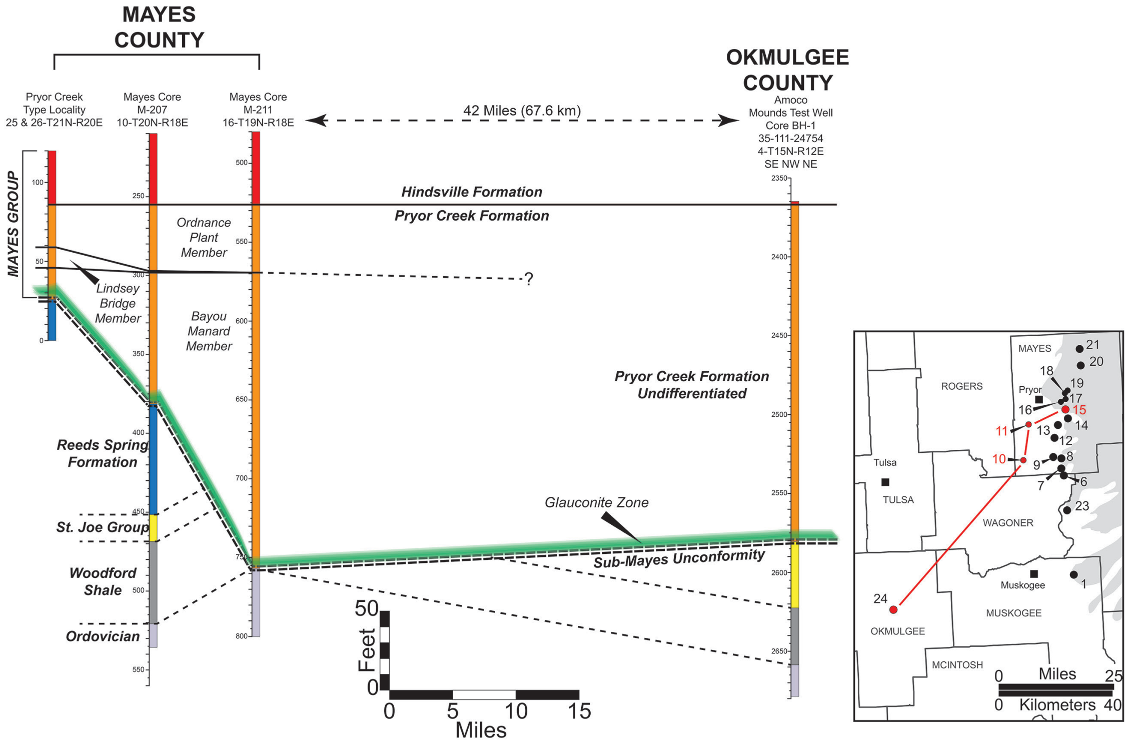


Figure 16. Cross-section from Mayes County southwest to Okmulgee County highlighting the correlation between expanded Pryor Creek Formation and truncation of older strata.

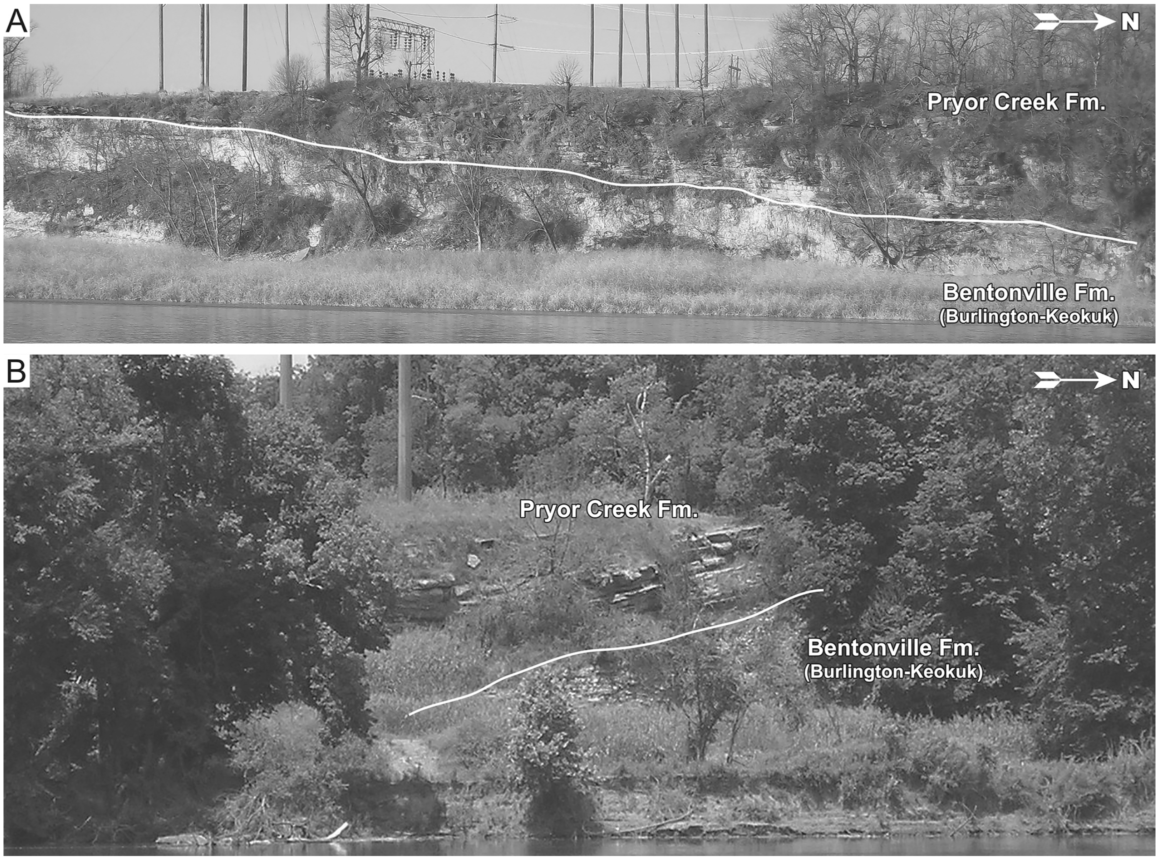


Figure 17. Outcrop photographs from the Ordnance Plant type locality demonstrating some of the large-scale paleotopographic relief at both the (A) north end and (B) south end. The Bayou Manard Member “drapes” over these highs. Moreover, the unconformity surface displays some dip and there is no clear evidence of truncation of the uppermost part of the Boone Group. Therefore, there is an overprinting of large-scale erosional relief by regional scale, structurally-controlled paleotopographic relief.

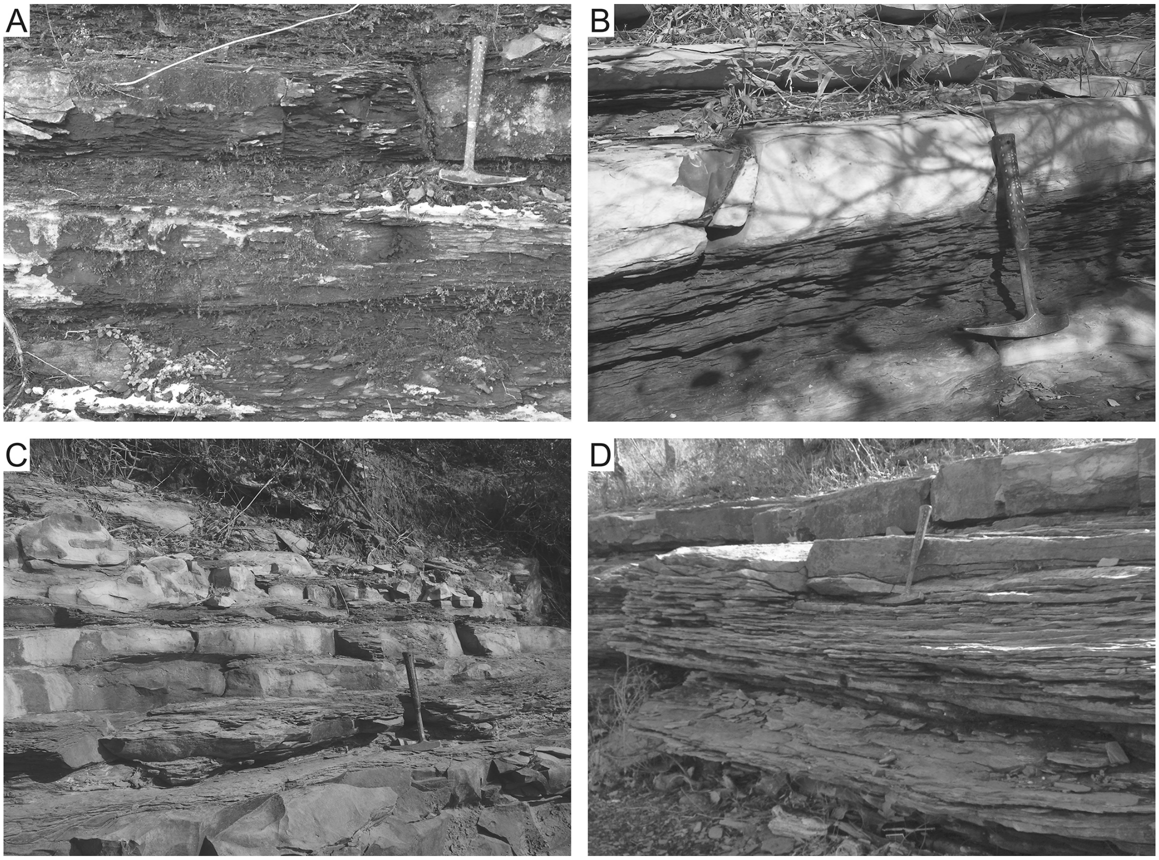


Figure 18. Common lithologies in the Bayou Manard Member. (A) Interbedded silty-shaly lime mudstone, microbioclastic wackestone-packstone, and silty calcareous shale at the Bayou Manard type locality. (B) Interbedded lime mudstone-wackestone (weathers light) and hard to platy calcareous shale/mudrock (dark) at the Lindsey Bridge type locality. (C) Lime mudstone at the Lindsey Bridge type locality. (D) Very thin to thin-bedded, platy, shaly lime mudstone-wackestone, silty-shaly microbioclastic wackestone-packstone, and calcareous shale at the base of the Bayou Manard Member at the Big Hollow R.A. locality. Rock hammer is 12 inches long.

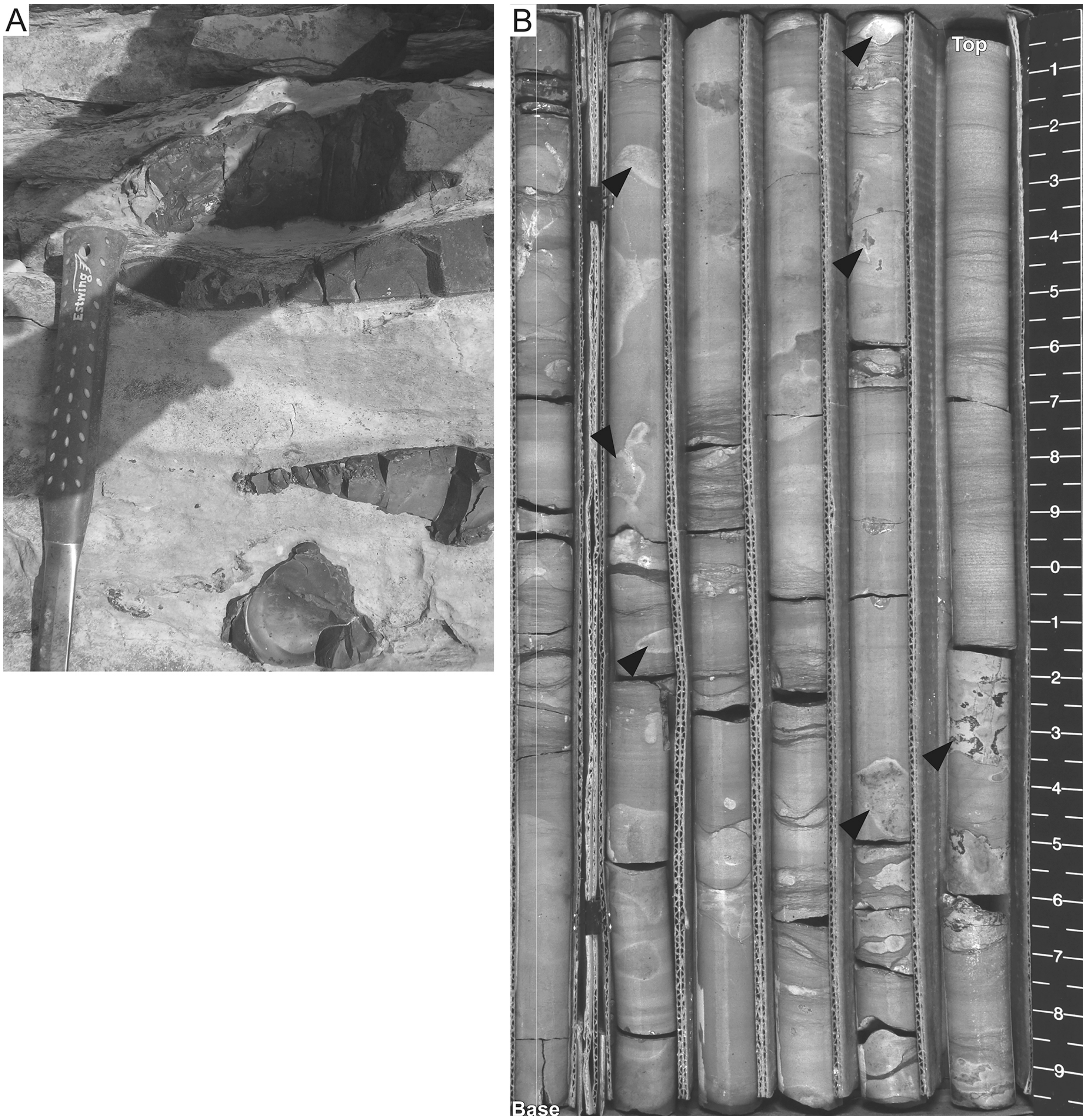


Figure 19. Chert in the Bayou Manard Member. (A) Black vitreous chert at the Lindsey Bridge type locality (handle of 12-inch rock hammer for scale). (B) Light to dark chert in Mayes County shallow sore M-205, similar to Reeds Spring Formation is several of the Mayes County shallow cores. Core interval is from 113.5 to 101.7 feet; core box length is 2 feet.

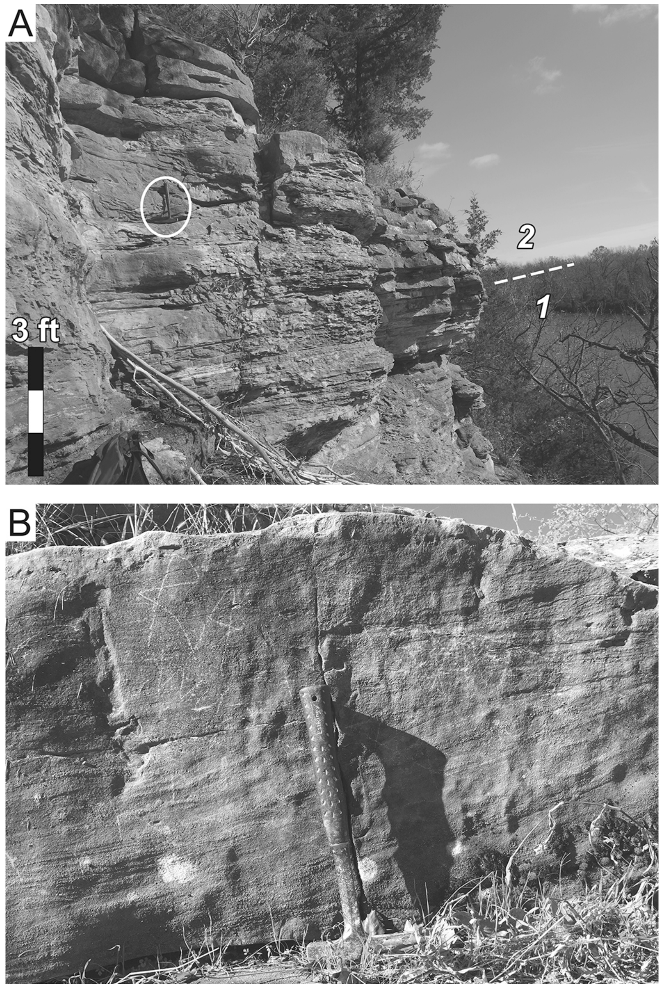


Figure 20. Lindsey Bridge Member lithologies. (A) Lindsey Bridge type locality, showing upward transition from (1) thin-bedded shaly-silty microbioclastic wackestone-packstone to medium-bedded fine to (2) coarse bioclastic packstone-grainstone (12-inch rock hammer in white circle for scale). (B) Internally cross-stratified coarse-grained bioclastic grainstone of the Lindsey Bridge Member at the Ordnance Plant type locality (12-inch rock hammer for scale).

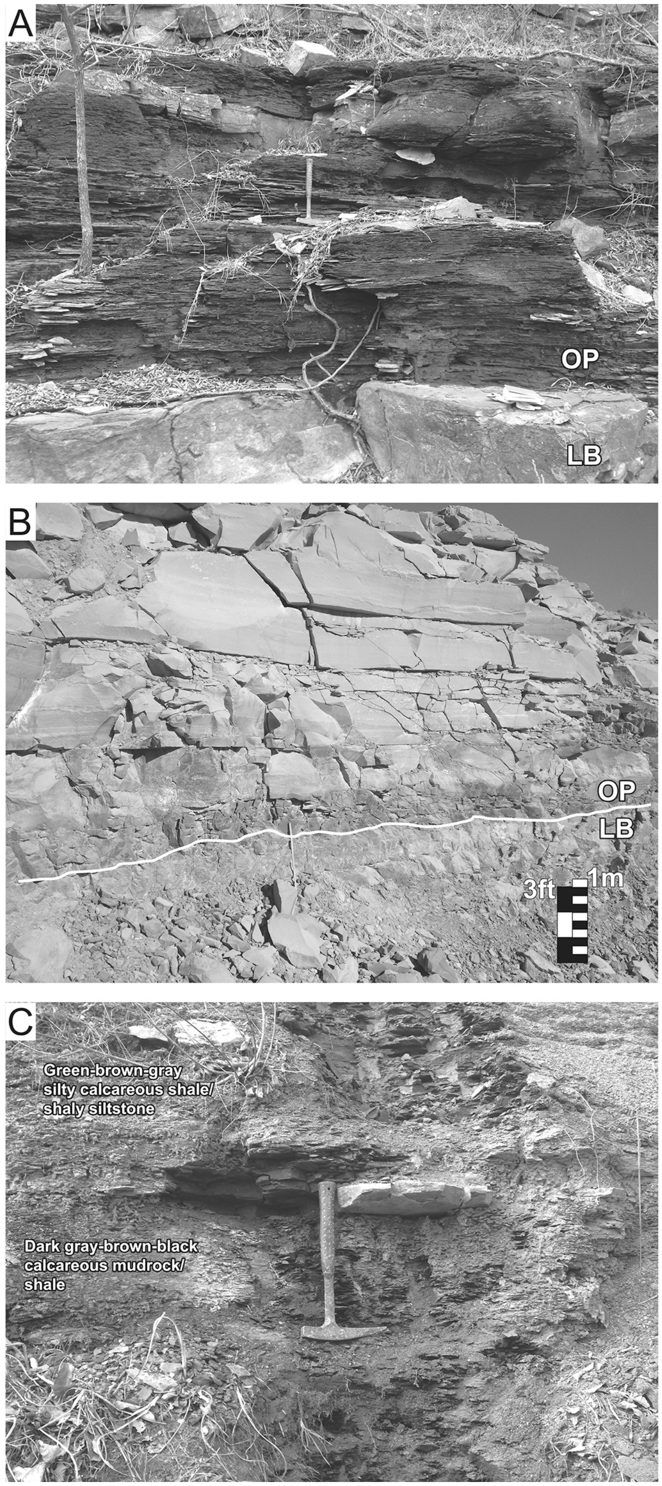


Figure 21. Ordnance Plant Member lithologies. (A) Lower phase consisting of dark brown-gray silty calcareous shale/shaly calcareous siltstone (Earbob R.A. locality). (B) Thick-bedded calcareous siltstone of the middle phase in the north high-wall at the Pryor Creek type locality. (C) Bidding Creek locality illustrating southward transition to more shale/mudrock lithologies within the Ordnance Plant Member within the middle phase siltstone as shown in (B). OP = Ordnance Plant Member, LB = Lindsey Bridge Member. 12-inch rock hammer for scale.

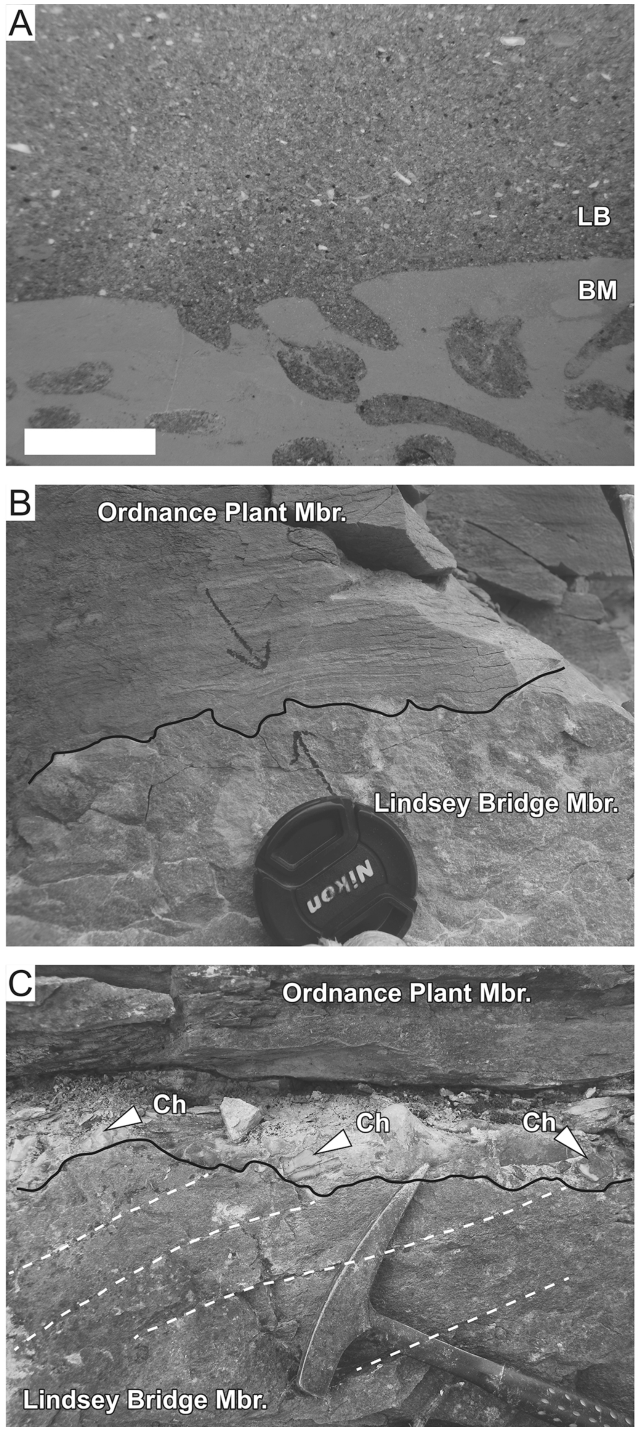


Figure 22. Important intraformational contacts of the Pryor Creek Formation. (A) Bayou Manard-Lindsey Bridge contact (Scale bar is 1 inch). (B) Lindsey Bridge-Ordnance Plant contact within the north high-wall section of the Pryor Creek type locality; lens cap diameter is 2 inches. (C) Lindsey Bridge-Ordnance Plant contact at the Stilwell Quarry locality, standard 12-inch rock hammer for scale.

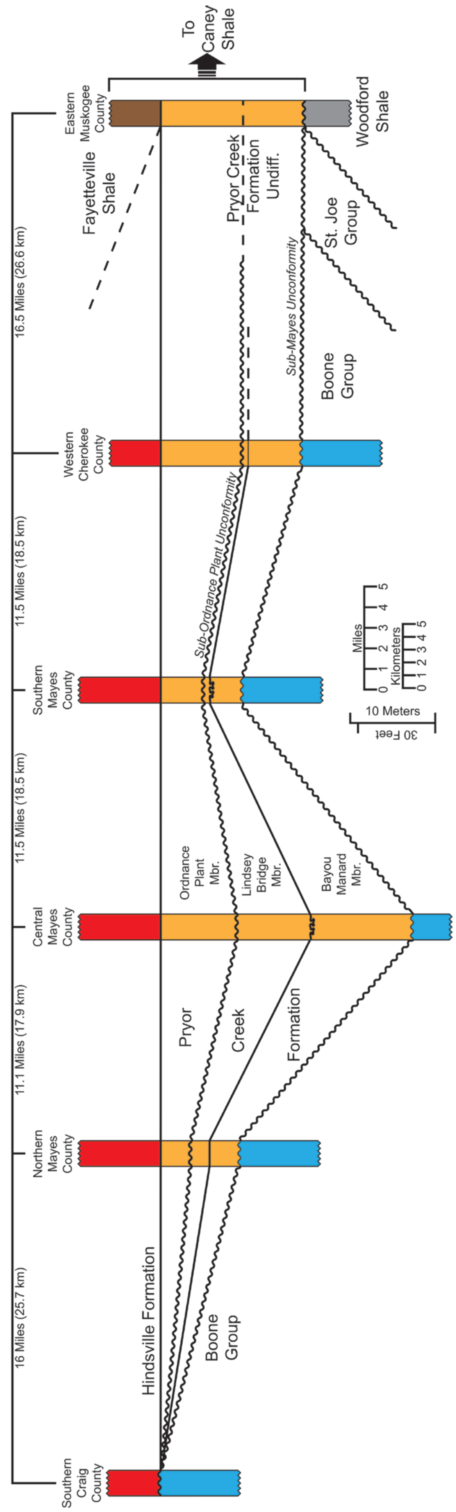


Figure 23. North-South regional cross-section along western edge of outcrop belt. Line of cross-section is shown in Figure 14.

CHAPTER III

MERAMECIAN-CHESTERIAN (UPPER VISEAN) CONODONT BIOSTRATIGRAPHY AND REVISED LITHOSTRATIGRAPHY ALONG THE SOUTHWESTERN FLANK OF THE OZARK UPLIFT, SOUTHERN MID-CONTINENT, U.S.A.

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ABSTRACT

Four conodont biozones, including three subzones, are interpreted within a revised lithostratigraphic framework for the upper Boone Group and Mayes Group in northeastern Oklahoma and adjacent parts of Missouri, Kansas, and Arkansas. Although revised lithostratigraphy is principally based on observed lithologic characteristics and stratigraphic relationships, conodont biostratigraphic data played an important role in correlation and final organization of units. Within the upper Boone Group, Biozone 1 (lower Meramecian) includes the Ritchey Formation and the Tahlequah Limestone and Biozone 2 (middle Meramecian) includes the Moccasin Bend Formation and Quapaw Limestone. The Mayes Group spans Biozone 3 and Biozone 4. Biozone 3 (upper Meramecian) is represented by the Bayou Manard Member of the Pryor Creek Formation (new name). Biozone 4 marks the appearance of definitive Chesterian conodont fauna. The lower two subzones within Biozone 4 correspond to the Lindsey

Bridge (Biozone 4L) and Ordnance Plant (Biozone 4M) members of the Pryor Creek Formation, whereas the upper subzone consists of the Hindsville Formation (Biozone 4U).

Documentation of conodont taxa and recognition of the proposed biozones provides relative time constraints for genetically-meaningful interpretations of regional geology and subsequent evaluation of the Mayes Group and upper Boone Group within a broader interregional context.

INTRODUCTION

Meramecian through Chesterian strata of the Mayes Group and upper Boone Group are exposed along the western edge of the Mississippian outcrop belt in northeastern Oklahoma and adjacent parts of Kansas, Missouri, and Arkansas. These rocks are under-evaluated and poorly understood in terms of both their regional stratigraphic framework and their roles within southern mid-continent geology. They are also important because time-equivalent strata are potential oil and gas producers to the west within the subsurface of Oklahoma. Correlations involving the Mayes Group and upper Boone Group across the outcrop belt and into the subsurface are numerous, equally variable, and largely lithostratigraphic in nature (Aurin et al., 1921; Buchanan, 1927; Brant, 1934, 1957; Cline, 1934; Laudon, 1935; Selk, 1948; Barker, 1950; Huffman, 1958; Ellzey, 1961; Harris, 1975; Boyd, 2008; Mazzullo et al., 2011; Mazzullo et al., 2014).

The primary purpose of this investigation was the construction of a refined regional stratigraphic framework for the Mayes Group and upper Boone Group in northeastern Oklahoma through the integration of conodont biostratigraphy and standard lithostratigraphy. Results reported herein include: (1) a revised regional lithostratigraphy, (2) the identification of four informal conodont biozones (including three subzones) and their correlation with established conodont zonation schemes of the Upper Mississippi River Valley, (3) the preliminary construction of a temporally-constrained stratigraphic framework within the study area, and (4) the evaluation of these strata within a broader interregional context through conodont-based correlations with time-equivalent strata in the southern mid-continent.

The current study is not directly concerned with subsurface stratigraphic problems in hydrocarbon producing areas of Oklahoma and Kansas. The results presented herein, however, provide a foundation for continued study of equivalent strata within the Mississippian outcrop area, as well as within the subsurface considering the position of study area along the transition between the surface and subsurface.

STUDY AREA AND METHODOLOGY

The study area encompasses the Mississippian outcrop area along the southwestern flank of the Ozark Uplift in northeastern Oklahoma, including the type Mayes Group area and Tri-State Mining District, the latter includes adjacent areas of southwestern Missouri and southeastern Kansas, and Arkansas (Figure 1). Also included within the study area are location 36 in Washington County, Arkansas and location 37 in Okmulgee County, Oklahoma. The former is included because it represents an important reference section within the Hindsville Formation type area, whereas the latter is included for its relevance to potential correlations of the Mayes Group into the subsurface of Oklahoma.

For this sample-based study, twenty-eight surface exposures and nine subsurface cores were examined, measured, described, and selectively sampled (Figure 1). For biostratigraphic analysis, bulk samples of at least two kilograms were taken from each sampled bed. The coarsest sampling interval used was meter-scale, with higher-resolution sampling of decimeter scale textural or lithologic changes. Higher-resolution sampling was applied at type and principal reference localities. Of the subsurface cores examined, only the PM-21 core in Cherokee County, Kansas and the MODOT B-49-8 core in Jasper County, Missouri were available for bulk sampling. Samples from cores were taken at regular intervals of decimeter-scale, while accounting for lithologic and textural boundaries. The processing of bulk samples for the recovery of conodonts followed the procedure of Collinson (1963).

PREVIOUS CONODONT STUDIES

Very little is published concerning the Meramecian through middle Chesterian conodont biostratigraphy within the study area. Branson and Mehl (1941a) described and illustrated the holotype of *Lochriea commutata* from the Hindsville Formation (reported by them as Pitkin Limestone) in Craig County, Oklahoma. Thompson (1972) examined conodonts from the Hindsville Formation, Fayetteville Shale, and Pitkin Limestone in Missouri, Arkansas, and Oklahoma. Grayson (1974, 1976) reported on conodont fauna of the Hindsville Formation in northern Arkansas. Goebel et al. (1968) described Mississippian conodont taxa from the Tri-State Mining District, although they questioned the presence of Meramecian Boone Group strata there. Thompson and Goebel (1969) summarized Mississippian taxa from across Kansas, including the Tri-State Mining District. In an unpublished thesis, Routh (1981) recovered conodonts from the Mayes Group at three locations in northeastern Oklahoma, including location 5 and location 14 of this report. Conodont specimens collected from surface exposures in northeastern Oklahoma and subsurface cores in northern Oklahoma during the 1960s by workers from the Amoco Research Center in Tulsa, Oklahoma were referenced or briefly discussed by Ormiston (1966), Selk and Ciriacks (1968), Selk (1973), and Brenckle et al. (1974).

REVISED LITHOSTRATIGRAPHY

It is necessary at this point to address proposed revision to Mayes Group and upper Boone Group lithostratigraphy within the study area (Figure 2). Inclusion of these revisions early in this report serves to introduce terminology and refined stratigraphic relationships, thereby avoiding confusion resulting from converting midway through this paper. Most of the following lithostratigraphic descriptions are based on physical observations and are independent of conodont biostratigraphic data. Conodont data supported certain facets of the revised lithostratigraphy presented below through the application of relative time-constrained regional correlations and interpretations. The impact of conodont data will be addressed following the description of conodont recoveries and the proposed informal biozones.

Snider (1915) defined the term “Mayes” for rocks stratigraphically positioned between the Osagean Keokuk Formation and the Chesterian Fayetteville Shale within Mayes County, Oklahoma. Huffman (1958) formally defined the Mayes Group and divided it into the “Moorefield Formation” and overlying Hindsville Formation, terms derived from their type areas in northern Arkansas. The “Moorefield Formation” in Oklahoma was subdivided by Huffman into the Tahlequah, Bayou Manard, Lindsey Bridge, and Ordnance Plant members, in ascending order. We herein propose the term Pryor Creek Formation (new name) as a replacement for the “Moorefield Formation” in Oklahoma, and include within it the Bayou Manard, Lindsey Bridge, and Ordnance Plant members. The Pryor Creek Formation is present throughout much of the Mississippian outcrop area of northeastern Oklahoma, south of the Tri-State Mining District. The Pryor Creek Formation in not currently continuous with the type Moorefield Formation of northern Arkansas across the Mississippian outcrop area, and questions remain as to whether the two were contiguous during deposition (Garner, 1967). Additionally, important lithologic differences exist between the Pryor Creek Formation and Moorefield Formation. The Pryor Creek Formation within the type area is defined by a generalized vertical succession of light brown-gray to dark gray lime mudstone-wackestone of the Bayou Manard Member, fine to very coarse-grained bioclastic packstone-grainstone of the Lindsey Bridge Member, and shaly calcareous siltstone of the Ordnance Plant Member. The Moorefield Formation, however, comprises goniatite-bearing dark brown-gray-black shale with some lenses of calcareous siltstone and limestone (Gordon, 1944; Garner, 1967; Handford, 1995). Although dark brown-gray-black shale is present within the Pryor Creek Formation and becomes more prominent as the unit is traced southward and westward from the type Mayes Group area of central Mayes County, it more closely resembles parts of the Caney Shale of southern Oklahoma to which it is geographically closer and with which it is interpreted as continuous (Huffman, 1958). Application of "Moorefield Formation" in Oklahoma is therefore confusing and commonly requires clarification as to which "Moorefield" is being discussed. The proposed type locality for the Pryor Creek Formation is the Pryor Quarry in central Mayes County (location 15) and the unit derives its name from the Pryor Creek tributary of the Grand River south of the town of Pryor (Figure 3). All or most of the unit is well exposed within several high-wall sections, including its lower and upper contacts, at location 15. Adjacent surface exposures and shallow subsurface cores in central Mayes County serve as valuable reference sections (locations 11-14 and 16-19). The base of the Mayes Group is a major unconformity, herein informally named the sub-Mayes unconformity Where the Pryor Creek Formation is present the unconformity is placed at the base of the Bayou Manard Member (Figure 4A), elsewhere the unconformity is placed at the base of the Hindsville Formation. The surface is sharp and irregular. Chert clasts derived from the Boone Group are distributed throughout the Mayes Group, but are commonly concentrated at or near the base. Huffman (1958) interpreted the boundary between the Moorefield Formation (Pryor Creek Formation of this report) and overlying Hindsville Formation as an unconformity based on the apparent truncation of the Ordnance Plant Member northward from central Mayes County, as well as a single surface section in which clasts believed to be derived from the Ordnance Plant Member were incorporated within the basal Hindsville Formation. This investigation yielded no conclusive evidence of an unconformity between the Pryor Creek Formation and Hindsville Formation and the contact is tentatively considered conformable (Figure 4B). An unconformity is herein interpreted between the Ordnance Plant and Lindsey Bridge members of the Pryor Creek Formation (Figure 4C), which differs from interpretations of earlier workers (Huffman, 1958; Turmelle, 1982). This contact is typically sharp and flat to irregular with iron and phosphate staining, clasts derived from the Lindsey Bridge Member incorporated into the basal Ordnance Plant Member, and truncation of the Lindsey Bridge Member. The basal Ordnance Plant Member is also characterized in some sections by an increased abundance of chert clasts derived from the Boone Group.

For reasons to be addressed later in this report, the Tahlequah Limestone (Tahlequah Member of Huffman, 1958) is excluded from the Mayes Group and included within the Boone Group. Conodont data played a substantial role in the change proposed for the Tahlequah Limestone, which displays a stronger faunal relationship to the upper Boone Group strata than to the Mayes Group. The principal reference section (location 3) for the Tahlequah Limestone (Figure 4D), is situated approximately 800 feet (240 m) southeast of the now poorly-exposed type locality defined by Huffman (1958). The Tahlequah Limestone is abundantly glauconitic, thin to thick-bedded, fine to medium-grained, bioclastic packstone-grainstone. Prior to its inclusion within the Mayes Group by Huffman (1958), the Tahlequah Limestone was informally referred to as the “glauconitic limestone member” of the Keokuk Formation (Bentonville Formation of this report) (Degraffenreid, 1953). In Cherokee County, Oklahoma the Tahlequah Limestone unconformably overlies Osagean Boone Group and is unconformably overlain by the Mayes Group.

Mazzullo et al. (2013) proposed the Ritchey Formation for cherty limestone above the lithologically similar Bentonville Formation of the Boone Group. Within the Oklahoma portion of the Tri-State Mining District, the Ritchey Formation replaces the “Baxter Springs Member” of McKnight and Fischer (1970), who included it within their “Boone Formation”. At its type locality in Newton County, Missouri (location 34), as well as location 21 in Jasper County, Missouri and location 30 in Cherokee County, Kansas, the Ritchey Formation is predominantly medium-bedded, very fine to coarse-grained bioclastic wackestone-packstone-grainstone, with lenses and discontinuous beds of light-colored chert. This description also applies to the Ritchey Formation at locations 30 and 31, as well as exposures of the unit in Boone County, Arkansas which are not included within this report (Mazzullo et al., 2013). In Ottawa County, Oklahoma and at locations 32 and 33 in Newton County, Missouri, however, two distinct lithologic phases within the Ritchey Formation are recognized in this study (Figure 5A). The “upper” phase of the Ritchey Formation is lithologically similar to typical Ritchey Formation to the north and east, as described above. In contrast, the “lower” phase of the Ritchey Formation is very cherty lime mudstone with lenses of bioclastic wackestone-packstone. In some instances, the “lower” Ritchey Formation consist entirely of chert, such as at location 26. A third lithologic phase of the Ritchey Formation is also recognized in Ottawa County, Oklahoma (Figure 5B). Informally termed the “Fairland facies”, it is named for exposures within a quarry east of the town of Fairland (location 22) and was included within the “K” bed (term of informal mining district usage) by McKnight and Fischer (1970) and considered by them to be correlative to rocks defined in this report as the “upper” phase of the Ritchey Formation. Although certain lithologic aspects of the “Fairland facies” are similar to those of the “upper” phase of the Ritchey Formation, there are significant differences. The “Fairland facies” at location 22 is 20-30 feet (6-9 m) of medium-bedded, massively cross-stratified, medium to very coarse, oolitic and bioclastic, packstone-grainstone, with abundant glauconite and siliceous sponge spicules. Lenses and discontinuous beds of chert, typically 2-6 inches (5-15 cm) thick, occur within the upper 5 feet (1.5 m) of the “Fairland facies”. The “lower” phase of the Ritchey Formation is absent at location 22. The Ritchey Formation unconformably overlies the Bentonville Formation (including Short Creek Oolite Member) (Mazzullo et al., 2013; Mazzullo et al., this volume). The base of the Ritchey Formation is commonly irregular, glauconitic, and mineralized (iron, silica, phosphate) (Figure 5C). At location 32 in Newton County, Missouri, the top of the Short Creek Oolite contains unlined burrows that appear to be passively-filled during deposition of the Ritchey Formation. At this same location, pebble-sized clasts of Short Creek Oolite Member are present within the basal Ritchey Formation. At location 22 in Ottawa County, Oklahoma, the Ritchey Formation truncates the upper Bentonville Formation, locally removing all of the Short Creek Oolite Member, and pebble-sized clasts of Short Creek Oolite Member are again present within the basal Ritchey Formation (Figure 5D).

McKnight and Fischer (1970) also included within their “Boone Formation” the “Moccasin Bend Member”, which is herein raised to formation rank and included within the Boone Group of Mazzullo et al. (2013). The type locality was defined by McKnight and Fischer (1970) and comprises a series of east-facing bluffs along the Spring River 6 miles (9.6 km) east of Miami, Oklahoma (location 25) (Figure 6A). Here, as much as 45 feet (14 m) of the Moccasin Bend Formation is cumulatively exposed, including the contact with the Ritchey Formation. The Moccasin Bend Formation typically consists of thin to medium-bedded lime mudstone and microbioclastic (silt-sized) to very fine-grained wackestone-packstone with minor to moderate glauconite and lenses to discontinuous beds of light to dark colored chert. Beds of white to light brown silicified limestone are common. Historically termed “cotton rock” and similar to tripolite elsewhere within the Boone Group (Mazzullo et al., 2013), these rocks are lightweight and contain oil-stained very fine moldic porosity (created from the dissolution of calcareous allochems) and microporosity within the silicified lime mudstone-wackestone matrix. The Moccasin Bend Formation is well exposed at several other localities along the Spring River (locations 24, 26, 28, and 29), in a roadcut at location 23 east of Wyandotte, and within a quarry east of Vinita in Craig County, Oklahoma (location 21). Contrary to the interpretation of McKnight and Fischer (1970), the base of the Moccasin Bend Formation is an unconformity along which a 2 to 18 inch (5 to 45 cm) thick zone of glauconitic and phosphate-rich shaly limestone with abundant chert clasts is present and is herein interpreted to be equivalent to the “J” bed of previous informal use within the Tri-State Mining District (Figure 6B) (Huffman, 1958; McKnight and Fischer, 1970).

The Quapaw Limestone conformably overlies the Moccasin Bend Formation and was defined by McKnight and Fischer (1970) for a single surface exposure in Ottawa County and interpreted occurrences in underground lead and zinc mines to the west. The Quapaw Limestone, however, was not included within the “Boone Formation” of McKnight and Fischer (1970), presumably due a lack of chert and mineralization. We propose including the Quapaw Limestone within the Boone Group of Mazzullo et al. (2013) based on its conformable relationship with the Moccasin Bend Formation. The type locality is incomplete and poorly-exposed, but the Quapaw Limestone is now well-exposed in a quarry (location 27) south of the town of Quapaw, which is herein designated as the principal reference locality (Figure 6C). Here, the Quapaw Limestone consists of 25 feet (8 m) of oil-stained, medium to thick-bedded, cross-stratified, fine to very coarse-grained, bioclastic (crinoidal) packstone-grainstone.

CONODONT RECOVERIES

Platform (P_1) elements were primarily used for this study, but we recognized the ultimate need for studies utilizing multi-element taxonomy. More than 14,000 specimens representing at least 22 identifiable platform species were recovered from more than 740 samples taken from the Mayes Group and upper Boone Group, as well as additional non-platform and unidentifiable specimens numbering more than 30,000. Platform species recovered include *Cavusgnathus altus* Harris and Hollingsworth (1933), *C. charactus* Rexroad (1957), *C. convexa* Rexroad (1957), *C. regularis* Youngquist and Miller (1949), *C. unicornis* Youngquist and Miller (1949), *Gnathodus bilineatus* (Roundy, 1926) (morphotypes 1 and 2), *G. girtyi girtyi* Hass (1953), *G. linguiformis* Branson and Mehl (1941b), *Gnathodus* n. sp. 15 aff. *punctatus* (Boardman et al., 2013), *G. pseudosemiglaber* Thompson and Fellows (1970), *Gnathodus* sp. A, *Hindeodontoides spiculus* (Youngquist and Miller, 1949), *Hindeodus cristula* (Younquist and Miller, 1949), *Lochriea commutata* (Branson and Mehl, 1941a), *L. homopunctatus* (Ziegler, 1960) (Atakul-Ozdemir et al., 2012), *L. mononodosus* (Rhodes et al., 1969), *Lochriea* sp. B, *Lochriea* sp. A, *Rhachistognathus* sp. B (morphotypes 1, 2, and 3), *Taphrognathus-Cavusgnathus* transitional form, *Taphrognathus varians* (Branson and Mehl, 1941b), and *Vogelgnathus campbelli* (Rexroad, 1957). Examples of the more significant form species are illustrated in Plate 1

Conodont elements were recovered from all lithostratigraphic units, albeit not from every sample taken. Samples from the Tahlequah Limestone, Ritchey Formation, Moccasin Bend

Formation, Quapaw Limestone, and Hindsville Formation consistently yielded stratigraphically useful specimens. Typical recoveries from the Pryor Creek Formation were sparse in comparison, and biozone definitions within the formation were based primarily on good recoveries throughout the Lindsey Bridge Member and near the bases of the Bayou Manard and Ordnance Plant members, as well as at the base of the Hindsville Formation. Recoveries from the “lower” and “upper” Ritchey Formation yielded an average of 8 P_1 elements per kilogram of rock sample, whereas recoveries from the “Fairland facies” averaged 36 P_1 elements per kilogram. Recoveries from the Tahlequah Limestone yielded more than 500 P_1 elements per kilogram. The Moccasin Bend Formation and Quapaw Limestone yielded averages of 23 and 12 P_1 elements per kilogram, respectively. Recoveries from the Bayou Manard and Ordnance Plant members of the Pryor Creek Formation were commonly 0 to 5 P_1 elements per kilogram, with better recoveries (as many as 255 P_1 elements per kilogram) near the base of each unit. The Lindsey Bridge Member yielded an average of 9 P_1 elements per kilogram. The Hindsville Formation yielded an average of 23 P_1 elements per kilogram.

CONODONT BIOSTRATIGRAPHY

Four informal biozones, including three subzones, were defined for the upper Boone Group and Mayes Group (Figure 7). Selected stratigraphic sections including taxonomic data used to define these biozones are illustrated in Figures 8 and 9. A strong correlation between the proposed biozones and current lithostratigraphic divisions is clearly evident in Figure 7. This is not surprising because most lithostratigraphic boundaries are disconformable and tend to introduce some degree of biostratigraphic bias through obstruction of the natural stratigraphic ranges of various taxa (Barrick and Mannik, 2005). This does not, however, diminish the utility of these biozones in terms of regional correlations, nor does it adversely affect comparisons of recovered taxa with those reported by other workers. It simply highlights the potential incompleteness of the stratigraphic record within the study area. Perhaps in more distal areas, where deposition was more continuous, variations of the ranges of selected taxa will be slightly different. Until this is explored in more detail, however, the proposed biozones below remain valid for two reasons. First, recoveries made during this investigation generally agree with those reported by previous workers within the study area. Second, an overall agreement exists between the observed ranges of important taxa recovered in this investigation and those reported in the established conodont zonation schemes of Collinson et al. (1971), Lane and Brenckle (2005), and Boardman et al. (2013)

Biozone 1 and Biozone 2

Biozone 1 includes the Ritchey Formation and Tahlequah Limestone and is defined by the first and only observed occurrence of *Gnathodus* n. sp. 15 aff. *punctatus* (Plate 1, Figure C; see also Boardman et al., 2013, pl. 15, fig 7) and *Gnathodus* sp. A (Plate 1, Figure A), as well as the first common occurrence of *Taphrognathus varians* (Plate 1, Figure D). Other species include *G. pseudosemiglaber* (Plate 1, Figure B), *G. texanus,* and *G. linguiformis*. Present in the Tahlequah Limestone, but not observed within the Ritchey Formation, were specimens of *Lochriea homopunctatus* (Plate 1, Figure M), which is the oldest known occurrence of this species in North America (Brenckle et al., 1974). Specimens herein designated *Gnathodus* sp. A were recovered alongside morphologically distinct specimens assigned to *G. pseudosemiglaber* (Plate 1, fig. 2) as defined by Thompson and Fellows (1970, p. 88-89; pl. 2, figs. 6, 8, 9, 11-13) and Thompson (1979). Specimens resembling *Gnathodus* sp. A were illustrated as *G. pseudosemiglaber* by Lane et al. (1980, pl. 4, figs. 15-17, and 19; pl. 5, figs. 8-15), Belka and Groessens (1986, pl. 7, figs. 1-3), Haywa-Branch, (1988, pl. 5, figs. 8-9), Perri and Spalletta (1998, pl. 1, fig. 14 and Pl. 2, fig. 12), and Blanco-Ferrera et al. (2005, p. 22, fig. 6, n. 27). Specimens similar to *Gnathodus* sp. A were interpreted by Belka and Groessens (1986, pl. 7, figs. 4 and 5) as transitional to *G. girtyi*, by Nemyrovska (2005, pl. 6, figs. 2, 3, 5, 6, and 8) as transitional between *G. pseudosemiglaber* and *G. girtyi meischneri*, and by Singh (2007, pl. 6, figs. 4-7) as primitive morphotypes of, or transitional to, *G. bilineatus*. The boundary between Biozones 1 and 2 is placed at the youngest observed occurrences of *Gnathodus* n. sp. 15 aff. *punctatus*, *G. pseudosemiglaber*, and *Gnathodus* sp. A, and the oldest observed occurrences of *Hindeodus cristula* and species of *Cavusgnathus* (Plate 1). Biozone 2 includes the Moccasin Bend Formation and Quapaw Limestone, and it is distinguished by the co-occurrence of *Taphrognathus* and *Cavusgnathus*. Other taxa recovered from Biozone 2 include *G. texanus* and rare *L. homopunctatus*. The top of Biozone 2 is defined by the youngest occurrence of *Taphrognathus*. Recoveries from the Moccasin Bend Formation were faunally more diverse than those from the Quapaw Limestone, the latter predominantly yielded specimens of *Cavusgnathus* and *Taphrognathus*.

Conodont taxa recovered from the upper Boone Group for this study largely confirm the age assignments of previous workers (Huffman, 1958; McKnight and Fischer, 1970), albeit with some important differences. Biozone 1 (Ritchey Formation and Tahlequah Limestone) is identical to the upper *texanus-Gnathodus* n. sp. 15 aff. *punctatus* Zone of Boardman et al. (2013) in terms of its interpreted stratigraphic range, but important differences include the identification of a potentially new species, *Gnathodus* sp. A, and inclusion of *L. homopunctatus* based recoveries from the Tahlequah Limestone. Recovery of *L. homopunctatus* from the Tahlequah Limestone, a species which extends into the Moccasin Bend Formation and younger strata, may indicate that the Tahlequah Limestone is slightly younger than the Ritchey Formation. Together, Biozones 1 and 2 are roughly equivalent to the *Taphrognathus varians-Apatognathus* Zone of Collinson et al. (1971) and the upper half of the *texanus* Zone of Lane and Brenckle (2005), and therefore provide a higher resolution division of otherwise long-ranging zones. Upper Boone Group strata are faunally similar to time-equivalent strata in the Upper Mississippi River Valley, Kansas, and Missouri (Rexroad and Collinson, 1963; Rexroad and Collinson, 1965; Goebel, 1968; Thompson and Goebel, 1969; Thompson and Fellows, 1970; Collinson et al., 1971; Thompson, 1986; Lane and Brenckle, 2005). The Ritchey Formation and Tahlequah Limestone (Biozone 1) are interpreted as early Meramecian in age, potentially latest Osagean, and partially equivalent to the Warsaw Formation of the Upper Mississippi River Valley. This interpretation generally agrees with those of previous workers (Cline, 1934; Huffman, 1958; McKnight and Fischer, 1970). The Moccasin Bend Formation and Quapaw Limestone (Biozone 2) are both early-late Meramecian in age and equivalent to the lower St. Louis Limestone of the Upper Mississippi River Valley based upon the co-occurrence of species of *Taphrognathus* and *Cavusgnathus* (Lane and Brenckle, 2005). In contrast, McKnight and Fischer (1970) considered the Moccasin Bend Formation to be Warsaw-equivalent and Quapaw Limestone to be Warsaw or possibly Salem-equivalent. Of note, the upper Salem is considered a facies equivalent of the lower St. Louis Limestone (Heckel, 2005).

Biozone 3

Biozone 3 includes only the Bayou Manard Member of the Pryor Creek Formation and is characterized by the occurrence of *Cavusgnathus* without *Taphrognathus*. Also marking the base of Biozone 3 is the oldest observed occurrence of *Hindeodontoides spiculus* (Plate 1, Figure G). Other taxa recovered include *Hindeodus cristula*, *Lochriea homopunctatus*, and *Gnathodus texanus*. Typical recoveries from the Bayou Manard Member yielded one to three specimens of *G. texanus*. The best recovery came from the lower five feet (1.5 m) of the Bayou Manard Member at locations in central Mayes County, including locations 13 and 14. Biozone 3 (Bayou Manard Member) is interpreted as roughly equivalent to the *Apatognathus scalensus*-*Cavusgnathus* Zone of Collinson et al. (1971) and the *scitulus-scalensus* Zone of Lane and Brenckle (2005). Absent from recoveries from the Bayou Manard Member were specimens of *Apatognathus scalensus* and *Hindeodus scitulus*, both of which are cited by Maples and Waters (1987) as diagnostic of the upper St. Louis Limestone. Therefore, correlation between Biozone 3 and established conodont zones is largely based upon the occurrence of *Cavusgnathus* without *Taphrognathus* and the first occurrence of *Hindeodontoides spiculus*, both of which are characteristic of the upper St. Louis Limestone of the Upper Mississippi River Valley and Kansas (Rexroad and Collinson, 1963; Goebel, 1968; Thompson and Goebel, 1968; Collinson et al., 1971; Lane and Brenckle, 2005).

Biozone 4

Biozone 4 includes the Lindsey Bridge and Ordnance Plant members of the Pryor Creek Formation and the overlying Hindsville Formation, each of which corresponds to one of three subzones (Figure 9). The boundaries between the Biozone 4 subzones are tentatively defined by subtle faunal variations. As a whole, Biozone 4 is defined by the first observed occurrences of definitive Chesterian taxa including *Gnathodus bilineatus*, *G. girtyi girtyi*, and *Lochriea commutata* (Plate 1, Figures E, N, Q, and R). Other taxa include *G. texanus*, *Hindeodus cristula*, *Hindeodontoides spiculus, L. homopunctatus*, and species of *Cavusgnathus*. Also defining Biozone 4 are occurrences of specimens resembling *Rhachistognathus muricatus* (Dunn). Defined for specimens recovered from the uppermost Mississippian (Upper Chesterian; Serpukhovian) through lowermost Pennsylvanian (Morrowan; Bashkirian) strata of Nevada (Dunn, 1965, 1970), *R. muricatus* has since been documented in time-equivalent strata throughout the western United States (Webster, 1969; Tynan, 1980; Wilson, 1982; Abplanalp et al., 2009), southern Oklahoma (Dunn, 1970; Lane and Straka, 1974), and Alaska (Kurka, 1997). Morphologically similar specimens were recovered from lower to middle Chesterian (Viséan) strata in the western United States (Tynan, 1980 as *Rhachistognathus* sp. A) and in the study area (Thompson, 1972 as *Spathognathodus muricatus*; Routh, 1981 as *Rhachistognathus lanei*). In all instances, the older Chesterian specimens are stratigraphically separated, by a gap in observed occurrence, from younger specimens of *R. muricatus* (Dunn) recovered within the same areas, thereby leaving questions as to their taxonomic relationship due to the unclear evolutionary lineage (Lane and Straka, 1974; Tynan, 1980). All recovered rhachistognathid specimens from the Mayes Group are herein referred to as *Rhachistognathus* sp. B, as not to be confused with

Rhachistognathus sp. A of Tynan (1980). At least two morphotypes of *Rhachistognathus* sp. B are recognized within the Mayes Group. Morphotype 1 (Plate 1, Figures K and L) includes those specimens whose carina is discontinuous and centrally located, whereas morphotype 2 (Plate 1, Figures I and J) includes those specimens whose carina appears to be continuous with the left margin. No clear distinction in the stratigraphic ranges of the two morphotypes was observed. Separation between the lower and middle subzones (4L and 4M), a boundary which corresponds to the base of the Ordnance Plant Member, is chiefly based on the first observed occurrences of the *G. bilineatus* (morphotype 1), which was not definitively recovered from the Lindsey Bridge Member during this investigation. Routh (1981), however, reported recovery of *G. bilineatus* from the Lindsey Bridge Member at the Lindsey Bridge type locality (location 14). First occurrences of *Lochriea* sp. A and *Lochriea* sp. B (Plate 1, Figures O and P) also define the boundary between subzones 4L and 4M, but were only recovered from the base of the Ordnance Plant Member (subzone 4M) at location 9 and location 7. Although both may simply represent morphologic variations within *L. homopunctatus*, future work could demonstrate their utility, so they are included here. The platform of *Lochriea* sp A. is very similar to that of *L. homopunctatus* in that it is mildly asymmetric and tapers posteriorly, but differs in that it is relatively unornamented except for one to three poorly-developed nodes. *Lochriea* sp. B also possesses a mildly asymmetric platform, but with distinctive ornamentation consisting of rows of nodes on each side of the carina that are slightly angled inward posteriorly. The ornamentation on *L. homopunctatus* also angles inward posteriorly, but is less organized. A single specimen identified as *L. mononodosus* was recovered from a sample within the Ordnance Plant Member at location 5. The boundary between the middle subzone (4M) and upper subzone (4U) is less definitive due to sparse recoveries within the upper Ordnance Plant Member and their overall faunal similarities. Subzone 4U is therefore defined by the first observed occurrence of *G. bilineatus* morphotype 2 and the apparent absence of *L. homopunctatus*. Subzone 4U also includes the first observed occurrence of *Vogelgnathus campbelli* (Norby and Rexroad, 1985) near the middle of the Hindsville Formation at location 36 in Washington County, Arkansas.

Biozone 4 generally corresponds to the early to middle Chesterian conodont zones of Collinson et al. (1971) and Lane and Brenckle (2005) based on the first occurrences of *G. bilineatus, G. girtyi girtyi*, *Rhachistognathus* sp. B, and *L. commutata*. A Chesterian age for these strata is in general agreement with interpretations of previous workers (Huffman, 1958; Thompson, 1972; Selk, 1973). Huffman (1958) did, however, interpret the Lindsey Bridge Member and Ordnance Plant Member as Meramecian in age and correlative to the St. Louis and Ste. Genevieve limestones, respectively. In the case of the Ordnance Plant Member, conodont recoveries of this study confirm its correlation with the Ste. Genevieve Limestone. However, we follow the interpretation of Maples and Waters (1987) who placed the Meramecian-Chesterian boundary at the base of the Ste. Genevieve, rather than include it at the top of the Meramecian. Placement of this boundary by Maples and Waters (1987) coincides with a significant faunal shift, which is easily recognized in this study by the first occurrence of several conodont species within Biozone 4, which also demonstrate that the Lindsey Bridge Member should be included in correlations with the Ste. Genevieve Limestone or equivalent lower Chesterian strata.

CONODONT BIOZONE TEMPORAL RESOLUTION

Conodont biozones represent relative time-constrained divisions of the rock record at higher temporal resolution than that provided by both the North American (Meramecian, Chesterian) and international (Viséan) chronostratigraphic divisions. The span of time represented by the upper Boone Group and Mayes Group is approximately 11 m.y. (Menning et al., 2006). The average length of time represented by each of the four proposed conodont biozones is therefore 2.7 m.y. per zone., which is generally comparable to the resolutions provided by the zonation schemes of Collinson et al. (1971) and Lane and Brenckle (2005). In addition, two of the zones of Lane and Brenckle (2005) extend into overlying or underlying strata and two of the zones of Collinson et al. (1971) are subdivided by the proposed zonal scheme of this report. Inclusion of Biozone 4 subzones provides a potential resolution of 1.8 m.y.

REGIONAL STRATIGRAPHIC FRAMEWORK

Important physical elements of the revised regional lithostratigraphy were outlined earlier in this report. Hence, the following discussion emphasizes the integration of biostratigraphy and lithostratigraphy and the role of conodont data in enhancing our understanding of the upper Boone Group and Mayes Group.

Two distinct biostratigraphicaly-constrained stratigraphic successions are present within the study area and define a revised regional stratigraphic framework (Figure 10). Both the Hindsville Formation and lower Boone Group are generally present throughout the study area, but important differences exist with regard to the rocks between them. In the Tri-State Mining District, strata of the upper Boone Group strata are present between the Hindsville Formation and Bentonville Formation, although upper Boone Group strata are locally absent due to erosion below the sub-Mayes unconformity. In the Tri-State Mining District, the Hindsville Formation overlies the Bentonville Formation at location 35, the Ritchey Formation at location 22, the Moccasin Bend Formation at location 21, and the Quapaw Limestone at location 25. In contrast, the Pryor Creek Formation is absent in the Tri-State Mining District, but it is widely distributed south of Craig County where upper Boone Group strata are largely absent below the sub-Mayes unconformity. In these areas, the Pryor Creek Formation most often overlies the Reeds Spring Formation or Bentonville Formation. In parts of Cherokee and Sequoyah counties the upper Boone Group is represented by the Tahlequah Limestone. Inclusion of the Tahlequah Limestone in the Boone Group is one of the more significant lithostratigraphic revisions presented earlier in this report. In addition to the physical evidence of an unconformity at the principal reference locality (location 3), conodont biostratigraphic data demonstrate separation of the Tahlequah Limestone (Biozone 1) and Mayes Group (Biozones 3 and 4) by a gap in time representing at least Biozone 2, further supporting the exclusion from the Mayes Group of the Tahlequah Limestone. Faunal similarities and correlation with the Ritchey Formation (Biozone 1) also support the inclusion of the Tahlequah Limestone within the Boone Group.

Upper Boone Group

The “lower” and “upper” phases of the Ritchey Formation are conformable and yielded similar Biozone 1 conodont taxa, thus a genetic relationship between them is inferred and they are interpreted as a minor shallowing-upward succession following the development of the sub-Ritchey unconformity (Mazzullo et al., this volume). The “lower” phase is absent to the north and east (locations 30, 31, and 34) due to the more proximal depositional positions of those sections, whereas sections containing both phases are in more distal positions within the Tri-State Mining District, assuming a general north-northeast to south-southwest depositional dip direction similar to that of older Mississippian strata (Lane and De Keyser, 1980). Occurrences of the “Fairland facies” and Tahlequah Limestone to the south-southwest of the two-phase Ritchey Formation are anomalous because both units display moderate to high-energy depositional characteristics and lack definitive evidence of low-energy deposition. Precise correlations between the “Fairland facies”, Tahlequah Limestone, and Ritchey Formation are below the current biostratigraphic resolution and an overall one-to-one correlation is therefore assumed. Based on the interpretation of McKnight and Fischer (1970), the “Fairland facies” exposed at location 22 remains tentatively correlated to the “upper” phase of the Ritchey Formation. Large-scale cross-stratification within the “Fairland facies” indicates a north-northeastward prograding depositional dip direction, opposite of that generally interpreted for Mississippian strata in this area. It is therefore possible that the “lower” phase of the Ritchey Formation represents low-energy back-barrier deposition in a relatively proximal position. The barrier in this case is a possible paleotopographic high, perhaps related to the Kanoka Ridge of Mazzullo et al. (this volume), along which the higher-energy “Fairland facies” of the Ritchey Formation was deposited. Lithologic comparison between the “Fairland facies” and Tahlequah Limestone suggest that the latter is a more distal expression of the former. Conodont abundance and diversity within the “Fairland facies” is greater than that of the both the “lower” and “upper” phases of the Ritchey Formation to the north and east, and the abundance and diversity within the Tahlequah Limestone is greater still. Although this represents a very simplified biofacies model, abundance and diversity trends within the “Fairland facies” and Tahlequah Limestone suggest the interpretation that they represent increasingly offshore and open marine conditions to the south, but without significant deepening, condensed sedimentation, or sediment starvation.

Together, the relatively low-energy Moccasin Bend Formation and high-energy Quapaw Limestone (Biozone 2) record a shallowing-upward succession and transition following the development of the sub-Moccasin Bend unconformity. Unlike the Ritchey Formation and Tahlequah Limestone, the Moccasin Bend-Quapaw succession is limited to the Oklahoma portion of the Tri-State Mining District due to a combination of erosion below the sub-Mayes unconformity and removal by modern erosion. Lack of surface exposures therefore limit our ability to address this relationship more fully at this time. Comparison of the Moccasin Bend Formation in sections of the Tri-State Mining District and the section exposed farther to the southwest at location 21 in Craig County indicated no evidence of deepening between the two areas. Because the Moccasin Bend Formation at location 21 is overlain by the sub-Mayes unconformity and Hindsville Formation, the original thickness of the Moccasin Bend Formation and possible deposition of Quapaw Limestone southwest of the Tri-State Mining District remains unknown. Additionally, the differences in faunal diversity between the Moccasin Bend Formation and Quapaw Limestone conform to their inferred relative depositional settings. Diverse fauna of the Moccasin Bend Formation, including specimens of *Lochriea homopunctatus*, suggests a more offshore setting (Burchette and Wright, 1992), whereas the predominance of *Cavusgnathus* and *Taphrognathus* in recoveries from the Quapaw Limestone suggest deposition within a shallow marine setting (Klapper and Barrick, 1978; Austin and Davies, 1984; Davies et al., 1994; Krumhardt et al., 1996).

Identification of the sub-Moccasin Bend unconformity was initially based on physical evidence outlined earlier in this report, but conodont data was critical in its subsequent correlation and interpretation. Erosion below the sub-Moccasin Bend unconformity includes an anomalous north-to-south truncation of the Ritchey Formation in Ottawa County, Oklahoma (Figure 11). At location 23 in Figure 11, a single 12-18 inch (30-45 cm) chert bed and 2 to 6 inches (5 to 15 cm) of shaly limestone are attributed to the Ritchey Formation between the Short Creek Oolite Member and Moccasin Bend Formation. Although the poorly-exposed beds above the sub-Moccasin Bend unconformity at location 23 may be easily misidentified as belonging to the "lower" phase of the Ritchey Formation, especially considering its vertical proximity to the top of the Short Creek Oolite Member. Conodont recoveries demonstrate that these strata are within Biozone 2 and are therefore the Moccasin Bend Formation.

Impact of Upper Boone Group Conodonts on Interpretations Involving the Lower Boone Group

Conodont recoveries from the upper Boone Group (Biozone 1 and Biozone 2) impact not only correlations of these strata, but also interpretations involving the lower Boone Group. Lithologic differentiation of the Ritchey and Bentonville formations, for example, is difficult in most places and the intervening Short Creek Oolite Member, when present and exposed, serves as a valuable stratigraphic marker (Thompson, 1986; Mazzullo et al., this volume). This is especially true where only the "upper" phase of the Ritchey Formation is present. Thompson (1986) designated the top of the Short Creek Oolite as the top of the Burlington-Keokuk and also as the Osagean-Meramecian boundary, but often this boundary is considered chiefly lithostratigraphic in nature. In addition to lithologic similarities, the Bentonville Formation and Ritchey Formation (including Tahlequah Limestone) are faunally similar based upon the observed ranges of forms attributed to *Gnathodus linguiform*is, *G. pseudosemiglaber*, *G. texanus*, and *Taphrognathus varians* (Thompson and Fellows, 1970; Rexroad and Collinson, 1965). Despite these similarities, a clear faunal distinction corresponding to the physical boundary between the Ritchey and Bentonville formations was recognized in this investigation and that of Boardman et al. (2013). Biozone 1 (Ritchey Formation) includes the first occurrences of *Gnathodus* n. sp. 15 aff. *punctatus* (Boardman et al., 2013) and *Gnathodus* sp. A of this report, as well as a significant increase in the occurrence of *T. varians*. Therefore, the contact between the Ritchey Formation and Bentonville Formation is more than lithostratigraphic in nature. It is a biostratigraphically-definable boundary within the study area, and potentially into the subsurface of Oklahoma.

Misidentification of the Moccasin Bend Formation as the Reeds Spring Formation by Laudon (1939) and Zeller (1950) in Ottawa County near location 24 of this study and by the senior author of the present paper (as presented in Mazzullo et al., 2013) at location 21 of this study in Craig County is the result of lithologic similarities between the two units. In the latter example from Craig County, the original interpretation as Reeds Spring Formation was based on lithology alone. Subsequent recovery of fauna representing Biozone 2 demonstrated that these strata are Moccasin Bend Formation, and definitely not Osagean in age. Although these mistaken identifications may simply be isolated incidents, it brings into question lithostratigraphic interpretations of Reeds Spring Formation strata outcropping in northeastern Oklahoma in sections without exposed regionally-recognized contacts.

Impact of Conodont Data on the Mayes Group of Northeastern Oklahoma

Within the Mayes Group, the greatest potential impact of conodont biostratigraphy is the refinement of intraformational correlations in the study area, especially away from the excellent surface and subsurface sections of central Mayes County and into areas where lithostratigraphic correlations break down due to combination of abundant incomplete sections and observed lithologic similarities between units of the Mayes Group. For example, lithologies that define the members of the Pryor Creek Formation are also present within the Hindsville Formation. An incomplete exposure consisting of lime mudstone, coarse-grained bioclastic packstone-grainstone, and calcareous siltstone may therefore represent the typical succession within the Pryor Creek Formation, but it may also represent the Hindsville Formation. Other examples include the occurrences of very fine-grained bioclastic packstone-grainstone (common to Lindsey Bridge Member) in the Bayou Manard and Ordnance Plant members, dark gray shaly lime mudstone-wackestone (similar to the Bayou Manard Member) in the Lindsey Bridge and Ordnance Plant members, and fine to coarse bioclastic wackestone-packstone-grainstone in the Ordnance Plant Member. Lithostratigraphic breakdown of this nature was described by Huffman (1958) and Turmelle (1982) as interfingering of facies, but may represent depositional cyclicity within the Mayes Group (Godwin and Puckette, 2015). Differentiation between units within the Pryor Creek Formation also becomes difficult to the south and west of central Mayes County, where these rocks are predominantly shaly. Although further work is needed, especially the collection of larger bulk samples due to the typically poor recoveries per kilogram, conodont biostratigraphic data may prove useful in subdividing and correlating sections of undifferentiated Pryor Creek Formation, or refining previous lithostratigraphic interpretations. A specific example is the section at location 5. Here, Huffman (1958) attributed as much as 28 feet (9 m) of the shale-dominated section to the Ordnance Plant Member. Initial conodont recoveries suggest that the Ordnance Plant Member, or at least strata attributable to Biozone 4M, may be restricted to only the upper 6 feet (2 m) of the section, with the underlying part of the section being in the Bayou Manard Member (Biozone 3).

Sub-Mayes Unconformity

The sub-Mayes unconformity is the most significant stratigraphic surface within this study because it is the only surface across which relative time, measurable within the resolution of the current biostratigraphic data, is clearly missing. All other unconformities within this study separate units representing successive conodont biozones. The Bayou Manard Member (Biozone 3) most commonly overlies the Osagean Reeds Spring and Bentonville formations, but it locally overlies the Tahlequah Limestone (Biozone 1) in Cherokee and Sequoyah counties and the Devonian Woodford Shale in southern Muskogee County (Huffman, 1958). In Mayes County core M-211 (location 10), the Pryor Creek Formation unconformably overlies Ordovician strata. Farther to the west, in Okmulgee County, the Pryor Creek Formation rests on the Lower Mississippian St. Joe Group in the Baker Hughes BH-1 core (location 37). In both the cores at location 10 and location 37, as well as the core at location 11, the Pryor Creek Formation is thicker than is typical across the western edge of the Mississippian outcrop belt. The Pryor Creek Formation is 229 feet (70 m) thick in the core at location 10 and 213 feet (65 m) thick in the core at location 37. In core M-207 (location 11) the Pryor Creek Formation rests unconformably on the Reeds Spring Formation and is 126.6 feet (38.6 m) thick. In contrast, the Pryor Creek Formation ranges between 0-95 feet (0-29 m) thick along its outcrop area in the northeastern Oklahoma. Expansion of the Pryor Creek Formation appears to occur primarily within the Bayou Manard Member. In parts of Adair and Cherokee counties in Oklahoma, the Pryor Creek Formation is also absent and the Hindsville Formation rests on Osagean Boone Group strata. Thickening of the Mayes Group at the expense of underlying Mississippian strata was discussed by previous workers in support of interpreted correlations between the Mayes Group and subsurface strata in Oklahoma informally known by as the “subsurface Mayes”, “Mississippi black limestone”, “Seminole Mayes”, or “Ada-Mayes” (Aurin et al., 1921; Buchanan, 1927; Brant, 1934; Cline, 1934; Laudon, 1948; Huffman and Barker, 1950; Huffman, 1958). Other workers believed the “subsurface Mayes” to represent a downdip facies of Kinderhookian or Osagean strata of Kansas and northern Oklahoma (Cram, 1930; Brant, 1934; Brant, 1957). Although restrictions prevented biostratigraphic sampling of the Mayes County shallow subsurface cores at locations 10, 11, and 16-19 and the Baker Hughes BH-1 core at location 37 in Okmulgee County, lithostratigraphic correlations appear to support correlation between the Mayes Group and “subsurface Mayes”, a section comprised of an expanded Pryor Creek Formation and distally-thinning Hindsville Formation. Assuming the unconformities observed at the bases of the Pryor Creek and Hindsville formations are correlative, the Mayes Group displays a general south-southwest truncation of older strata and filling of post-Boone accommodation space by a basinward thickening Pryor Creek Formation (primarily the Bayou Manard Member).

INTERREGIONAL CORRELATIONS IN THE SOUTHERN MID-CONTINENT

Interregional correlations are discussed below and are the product of comparisons between recovered conodont taxa, proposed biozones, and interpretations of this study and those of previous workers. These biostratigraphically-constrained comparisons suggest that the stratigraphic architecture of northeastern Oklahoma is an expression of a common theme throughout the southern mid-continent. In short, in many parts of the southern mid-continent, Meramecian and older strata are locally to regionally absent below a major unconformity (sub-Mayes unconformity) and are overlain by basinward-thickening successions.

Away from the study area, few strata time-equivalent to upper Boone Group (Biozone 1 and Biozone 2) are recognized within the southern mid-continent. A summary of these correlations are illustrated in Figure 13. In addition to this study, Warsaw through St. Louis strata are commonly recognized in both Kansas and Missouri and are considered to be generally contiguous with those of the Upper Mississippi River Valley (Goebel, 1968; Thompson and Geobel, 1969; Thompson 1986). Strata equivalent to Biozone 1 and Biozone 2 are also present in southern New Mexico and west Texas (Lane, 1974; De Keyser et al., 1985) and in the Texas panhandle (Ruppel and Lemmer, 1986), areas which are situated along the Lake Valley Shelf and Chappel Shelf, respectively, and represent southwestward extension of the Burlington Shelf (Lane and De Keyser, 1980; Gutschick and Sandberg, 1983). Along the Llano Uplift of central Texas, within the Chappel Shelf area, the Barnett Shale (Chesterian) is underlain by the White's Crossing Limestone of Osagean to Meramecian age, which in turn rests on the Kinderhookian-

Osagean Chappel Limestone (Hass, 1953, 1959; Turner, 1957; Grayson and Merrill, 1991). Conodont specimens illustrated by Singh (2007, pl. 6, figs. 4-7) from the White's Crossing Limestone are very similar to *Gnathodus* sp. A of this study and suggest possible correlation to Biozone 1.

Unlike the upper Boone Group (Biozone 1 and Biozone 2), to which few identified strata within the southern mid-continent are correlative, biostratigraphically-constrained correlations between the Mayes Group and a number of time-equivalent strata in the southern mid-continent are clearly evident. Based on taxa recovered during this investigation and evaluation of those reported by previous workers (Roundy, 1926; Hass, 1953; Schwartzapfel, 1990; Boardman and Puckette, 2006; Singh, 2007), the Hindsville Formation (Biozone 4U) is correlative to the Delaware Creek Member of the Caney Shale of southern Oklahoma and the lower Barnett Shale of central Texas. In addition, the Fayetteville Shale has been correlated to the Sand Branch Member of the Caney Shale and upper Barnett Shale (Thompson, 1986). Furthermore, ammonoid-based correlations between the Hindsville Formation, Fayetteville Shale, Caney Shale, and Barnett Shale generally support those based on conodont data (Saunders, 1973). Conodont recoveries from the Lindsey Bridge and Ordnance Plant members of the Pryor Creek Formation (Biozones 4L and 4M) suggest they should be included in interregional correlations of the Hindsville Formation. Subzones proposed within Biozone 4, however, are not recognized outside of the current study area. Chesterian strata equivalent to Biozone 4 are interpreted within the Rancheria Formation of west Texas and southern New Mexico (Lane, 1974) and in Kansas (Goebel, 1968). Despite lack of published conodont recoveries from the Moorefield Formation of northern Arkansas, it is considered correlative to the Pryor Creek Formation based on historic correlations of benthic macrofauna (Girty, 1909; Gordon, 1944; Huffman, 1958) and ammonoid-based correlations of Moorefield Formation to the Caney Shale and Barnett Shale (Saunders 1973), to which Lindsey Bridge and Ordnance Plant members (Biozones 4L and 4M) are herein correlated.

Unconformities and stratigraphic relationships comparable to the sub-Mayes unconformity are present elsewhere within the southern mid-continent, recording a common theme of expanded post-unconformity sections at the expense of pre-unconformity section (Figure 12). In the subsurface of north-central Oklahoma, Selk (1973) and Selk and Ciriacks (1968) reported recoveries of St. Louis conodont fauna, interpreted as belonging to the Bayou Manard Member, from cores in Grant, Major, Noble, Osage, Pawnee, and Payne counties. These St. Louis conodont faunas were recovered from rocks overlying and underlying strata yielding Kinderhookian and Chesterian conodonts, respectively. In Boone County, Arkansas, the Moorefield Formation is absent and the Hindsville Formation rests unconformably on the Ritchey Formation of the Boone Group (Laudon, 1948; Mazzullo et al., 2013). To the east-southeast, the Moorefield Formation unconformably overlies the Boone Group, conformably underlies the Hindsville Formation/Batesville Sandstone, and thickens distally to the south and southeast (Handford, 1995). Furthermore, thinning of both the Moorefield Formation and the Pryor Creek Formation towards the Oklahoma-Arkansas state line suggest that area was possibly a positive feature during deposition of the two units and the two units were not depositionally contiguous. In southern New Mexico, an unconformity was interpreted between the Rancheria and Lake Valley formations, with the former thickening to the south at the expense of the latter (Lane, 1974; Greenwood et al., 1977; Bachtel and Dorobek, 1998). Along the Llano Uplift, the Barnett Shale overlies the Chappel Limestone (Kinderhookian-Osagean) (Hass, 1953, 1959; Singh, 2007; Boardman et al., 2012). Previous workers have interpreted the contact between the Barnett Shale and Chappel Limestone as conformable (Zachry, 1969; Montgomery et al., 2005). Grayson and Merrill (1991, fig. 21), who also interpreted a physically-conformable relationship, but reported Chesterian taxa consistent with Biozone 4 of this study at the base of the Barnett Shale, directly above the Chappel Limestone containing Kinderhookian-Osagean taxa. Regardless of the physical expression of the unconformable contact, a clear biostratigraphically-constrained time gap exists between the Barnett Shale and Chappel Limestone spanning much or all of the

Meramecian and Osagean, without evidence of condensed sedimentation (Hass, 1953, 1959; Singh, 2007). Traced into the subsurface of the Fort Worth Basin, the Barnett Shale thickens and overlies Ordovician strata (Montgomery et al., 2005). In the northern Arbuckle Uplift area, the Ahloso Member of the Caney Shale unconformably overlies the Kinderhookian-Osagean Welden Limestone, but to the south it overlies the Woodford Shale (Elias, 1956). In the southern Arbuckle Uplift area, the Ahloso Member is absent and the Sycamore Limestone unconformably overlies the Woodford Shale. Overlying the Sycamore Limestone are strata interpreted as the Delaware Creek Member of the Caney Shale (Elias, 1956; Haywa-Branch, 1988; Schwarzapfel, 1990). The Stanley Shale of southern Oklahoma also unconformably overlies the Woodford Shale (Hass, 1950, 1951; Laudon, 1959).

In addition to the basal unconformity, many of the post-unconformity strata discussed above share similar conodont faunal characteristics. Recoveries from the Bayou Manard Member are typically dominated by *Gnathodus texanus*, and those at or near the base of the unit contain reworked taxa, including Osagean *G. bulbosus* Thompson (1967) and *G. pseudosemiglaber*. Stratigraphic mixing due to unconformity-related reworking occurs within lowermost Sycamore Limestone (Ormiston and Lane, 1976; Schwartzapfel, 1990) and Ahloso Member of the Caney Shale (Haywa-Branch, 1988; Haywa-Branch and Barrick, 1990). The Ahloso Member is the least biostratigraphically-constrained part of the Caney Shale, but, as part of ongoing research representing an extension of this investigation, two samples were taken from the Ahloso Member of the Caney Shale at the Hass 'G' locality in Pontotoc County, Oklahoma. These samples were taken from two brachiopod-rich calcareous and shaly siltstone beds approximately 3.5 feet (1 m) and 7 feet (2 m) above the interpreted top of the Welden Limestone. Recoveries from the lower brachiopod bed were dominantly composed of specimens attributable to *G. texanus.* Recoveries from the upper brachiopod bed also included *G. texanus*, but also yielded *G. bilineatus*, *Rhachistognathus* sp. B, and *Lochriea commutata*. Based on these recoveries, the upper brachiopod bed is correlative with Biozone 4, whereas those of the lower brachiopod bed are similar to those of Biozone 3, if only due to the predominance of *G. texanus*. Poor recoveries, predominantly consisting of forms interpreted as *G. texanus* were also reported from the lowermost Stanley Group and subsequently overlain by strata containing *G. bilineatus* (Hass, 1950; 1951). Although the Barnett Shale is clearly Chesterian in age, some workers have interpreted an Osagean or Meramecian age, at least within the basal part (Ellison, 1989), possibly due to stratigraphic mixing. Above the unconformity at the base of the Las Cruces and Rancheria formations, Lane (1974) indicated that the oldest conodont recoveries consisted of *G. texanus* with no conclusively younger taxa, and were consequently considered to be late Osagean through early Meramecian. This zone was reportedly overlain at one locality by a zone consisting of *G. texanus*, *Cavusgnathus altus*, the *Taphrognathus-Cavusgnathus* transitional form, and reworked Kinderhookian-Osagean taxa, suggesting correlation with at least Biozone 2, if not Biozone 3 due to the lack of definitive specimens of *Taphrognathus* (Lane, 1974).

SYNDEPOSITIONAL TECTONISM

Interpretations of stratigraphic architecture within the southern mid-continent have been tied to early phases of Ouachita tectonism. To explain the absence of Kinderhookian and Osagean strata in parts of the southern mid-continent, Noble (1993) interpreted a lower Mississippian depositional hiatus stemming from sediment starvation and localized erosion associated with changing marine circulation during early phases of Ouachita tectonism. A similar lack of Meramecian strata (Biozones 1 and 2) within the southern mid-continent was noted by Noble (1993) and is evident from comparisons of conodont recoveries reported by others with those recovered from the upper Boone Group in this study. In recent work by Mazzullo et al (2011), Boardman et al. (2013), and Mazzullo et al. (this volume) anomalous Kinderhookian and Osagean stratigraphic architecture is attributed to periodic fore-bulge uplift and relaxation associated with early Ouachita tectonism and lack evidence indicative of sediment starvation and condensed sedimentation to the south and southwest of the Mississippian outcrop area. Likewise, development of the sub-Ritchey and sub-Moccasin Bend unconformities and the distribution of depositional facies within the upper Boone, interpreted within the constraints of provided by the proposed biozones, display some anomalous stratigraphic relationships and lack definitive deepening profiles into a starved basin area as would be expected in the model proposed by Noble. Thus, evidence from the upper Boone Group, including development of the high-energy “Fairland facies” along a possible paleotopographic high within the southwestern part of the Tri-State Mining District, erosional remnants of Biozone 1 (Tahlequah Limestone) farther southward, and the southward truncation of the Ritchey Formation by the sub-Moccasin Bend unconformity, support the interpretation of syndepositional tectonism associated with fore-bulge flexure and relaxation.

Furthermore, high-energy facies of the Lindsey Bridge Member at locations 14 and 15 in central Mayes county displays northeastward progradation, which was first noted by Swinchatt (1967) in his evaluation of the unit at location 14. Northeastward progradation of the Lindsey Bridge Member is associated with observed thinning of both the Lindsey Bridge and Bayou Manard members across a paleotopographic high at location 13 at which a remnant of the Bentonville Formation is present above the Reeds Spring Formation (Figure 13). The sub-Mayes unconformity and its interregional correlative unconformities represent a significant event within the southern mid-continent, and it is below this unconformity that the widespread hiatus cited by Noble (1993) is commonly placed. The wide range of strata below the sub-Mayes unconformity, which range from Ordovician through Middle Mississippian (Meramecian) indicates that uplift and erosion played a more significant role in the development of the hiatus than did sediment starvation and/or erosion by geostrophic currents as suggested by Noble.

SUMMARY

In the simplest terms, conodont biostratigraphy provides one method by which rocks are constrained in relative time and more accurately correlated, regardless of the inherent limitations of basic lithostratigraphy, including incomplete sections, complex or anomalous stratigraphic relationships, and lithologic similarities between temporally-distinct strata. Although we recognize the potential for stratigraphic architecture below the resolution of current conodont biostratigraphic data, the proposed biozones still provide an improved set of temporally-constrained boundaries between which those higher-resolution architecture and facies distributions may be interpreted. Conodont biozones proposed for the upper Boone Group and Mayes Group therefore improve lithostratigraphically-based interpretations and correlations within the study area and allow for their evaluation within a broader interregional context.

During this investigation a number of key observations were made that potentially impact surface and subsurface correlations and geologic interpretations within the southern mid-continent:

1. Meramecian through middle Chesterian (post-Osagean/pre-Hindsville) rocks are present along the westernmost edge of the Mississippian outcrop belt and represent potentially important surface analogs for under-evaluated components of the complex subsurface Mississippian section of Oklahoma.
2. Within the study area of northeastern Oklahoma, the regional stratigraphic framework includes important temporal and genetic distinctions between the stratigraphic succession of the Tri-State Mining District where upper Boone Group (Biozones 1 and 2) strata are present and the succession to the south where those strata are absent and the Pryor Creek Formation (Biozones 3, 4L, and 4M) is present below the Hindsville Formation.
3. The importance of the above geographic distinction within the study area is exemplified by relationship between the Bayou Manard Member (Pryor Creek Formation) and the Moccasin Bend Formation. Both are broadly considered equivalent to the St. Louis Limestone and are underlain by unconformities, yet the two units are faunally distinct. Therefore, a broad-brushed correlation of these units with the St. Louis Limestone is misleading. The Moccasin Bend Formation and Quapaw Limestone (Biozone 2) are

equivalent to the lower St. Louis Limestone and upper Salem Limestone, whereas the Bayou Manard Member (Biozone 3) is equivalent to the upper St. Louis Limestone. These faunal differences are documented elsewhere, including within the Upper Mississippi River Valley.

4. Globally-correlative sea-level falls were interpreted by Ross and Ross (1985) both before and after deposition of the lower St. Louis Limestone/upper Salem Limestone. Thus, the unconformity at the base of the Moccasin Bend is herein interpreted to be associated with pre-St. Louis sea-level fall and potentially correlative to the sub-"St. Louis" unconformity of Witzke et al. (1990), whereas the sub-Mayes unconformity appears to correspond to a mid-St. Louis sea-level fall.
5. Separation between the upper Boone Group section of the Tri-State Mining District and the Mayes Group-dominated area to the south is marked by the sub-Mayes unconformity and expansion of parts of the Mayes Group at the expense of pre-Mayes strata.
6. Temporal and genetic separation between the Tahlequah Limestone (Biozone 1) and the Pryor Creek Formation (Biozones 3 and 4) across the sub-Mayes unconformity, along with faunal correlation between the Tahlequah Limestone and Ritchey Formation (Biozone 1), supports the removal of the Tahlequah Limestone from the Mayes Group and its subsequent inclusion within the Boone Group. Occurrences of the Tahlequah Limestone south of the Tri-State Mining District represent erosional remnants below the sub-Mayes unconformity.

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FIGURES

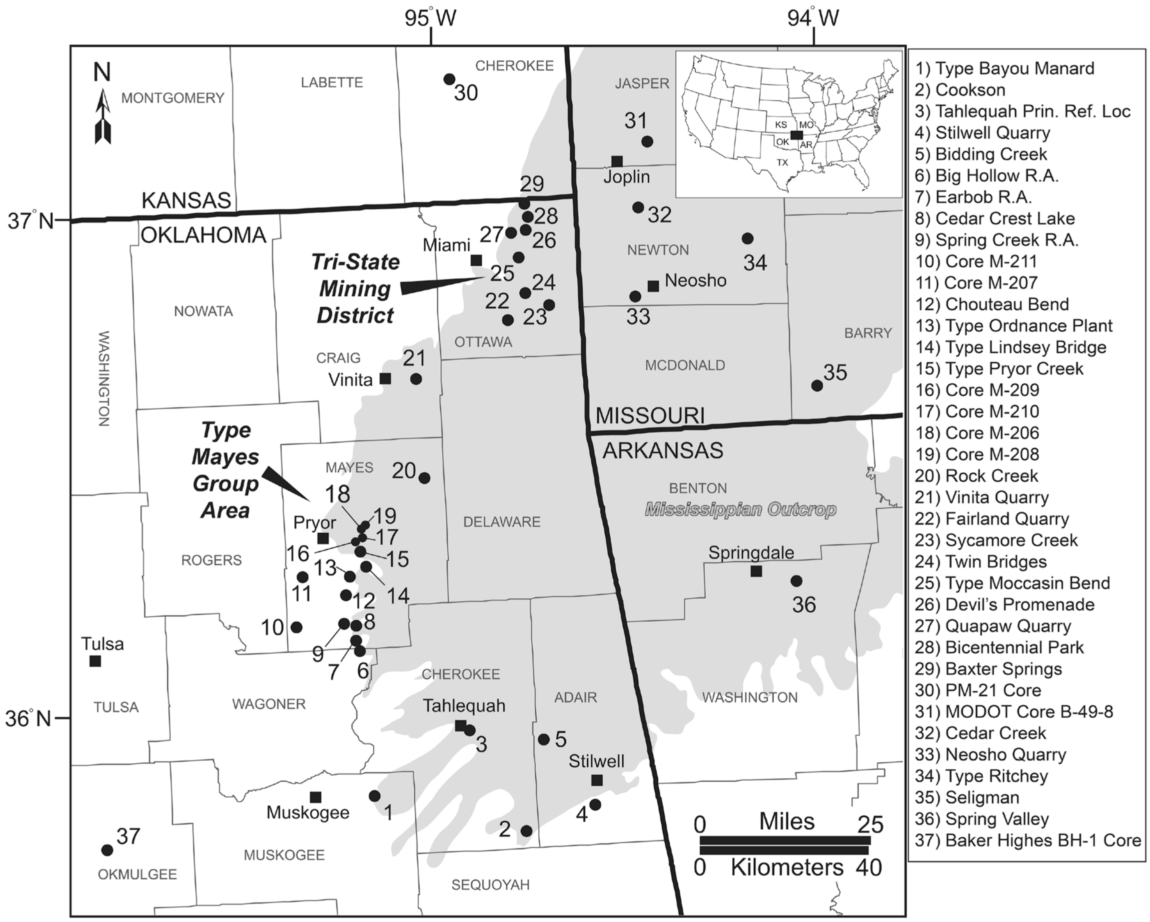


Figure 1. Regional study area map with locations of reference sections discussed in the text. Gray shaded area represents Mississippian outcrop belt.

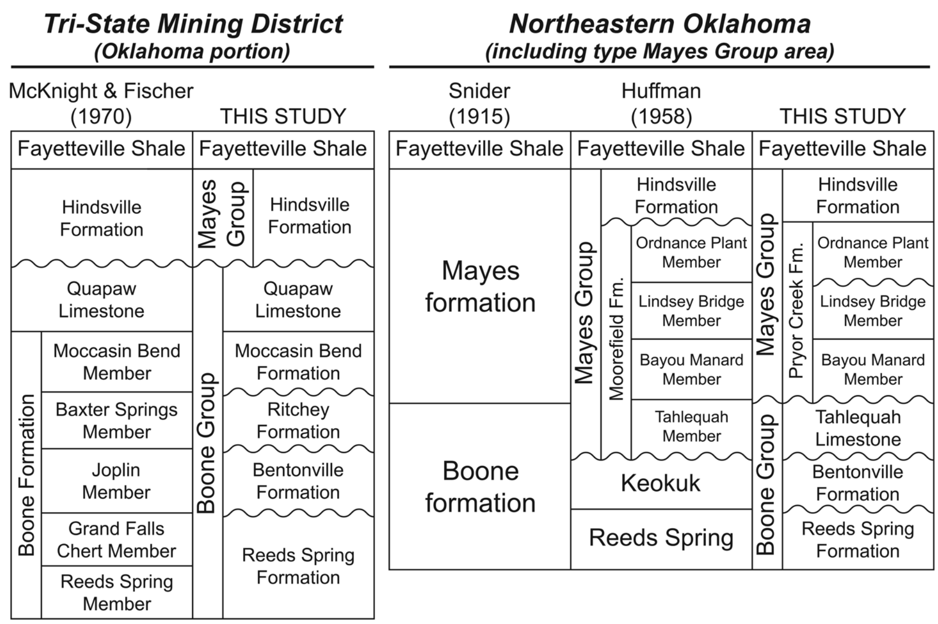


Figure 2. Proposed lithostratigraphic nomenclature and stratigraphic relationships and relevant historical lithostratigraphy.

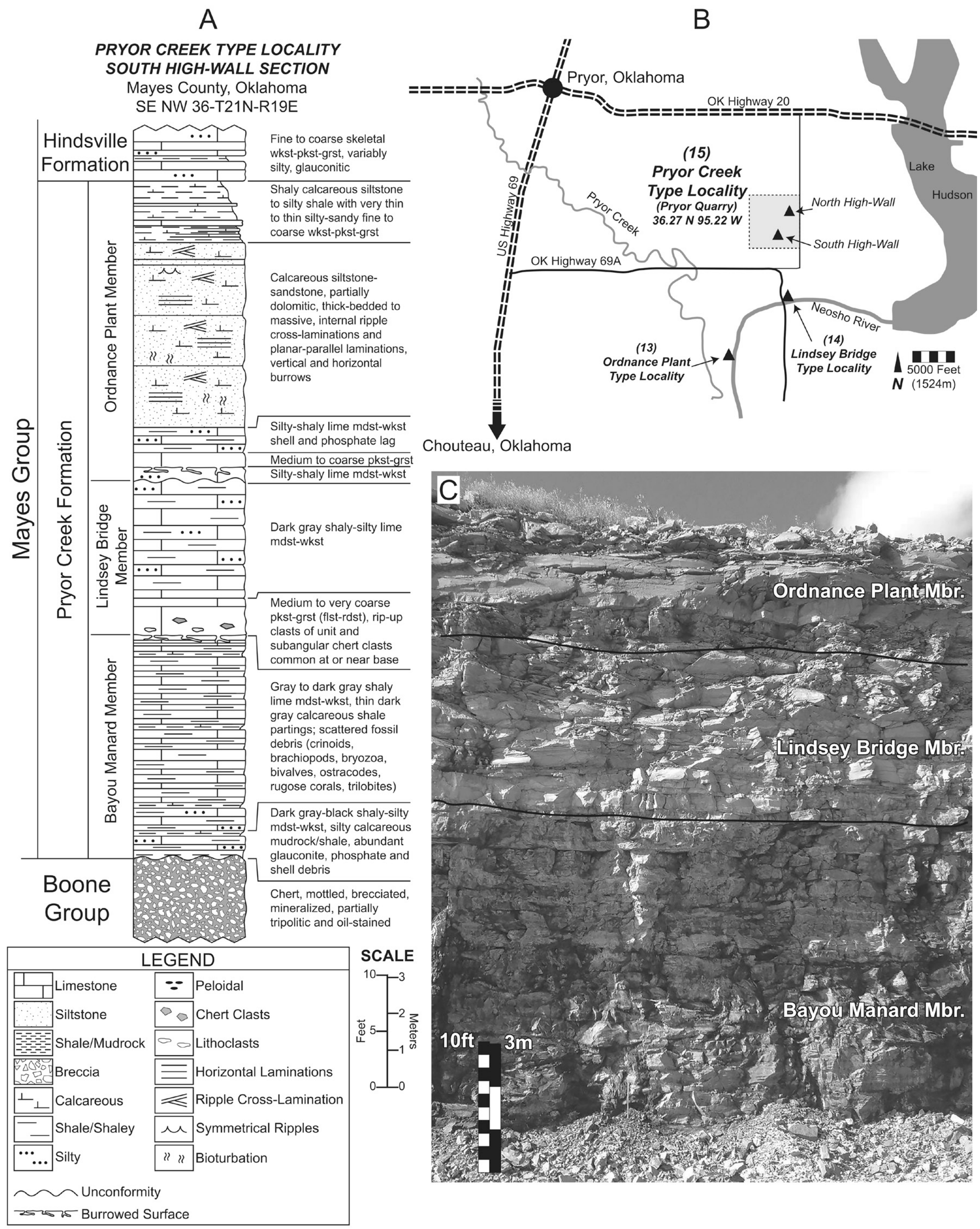


Figure 3. (A) Pryor Creek Formation type section from south quarry high-wall. (B) Pryor Creek type locality location map. Including relative positions of important reference sections. Location numbers in parentheses. (C) Outcrop photograph of main part of south high-wall section.

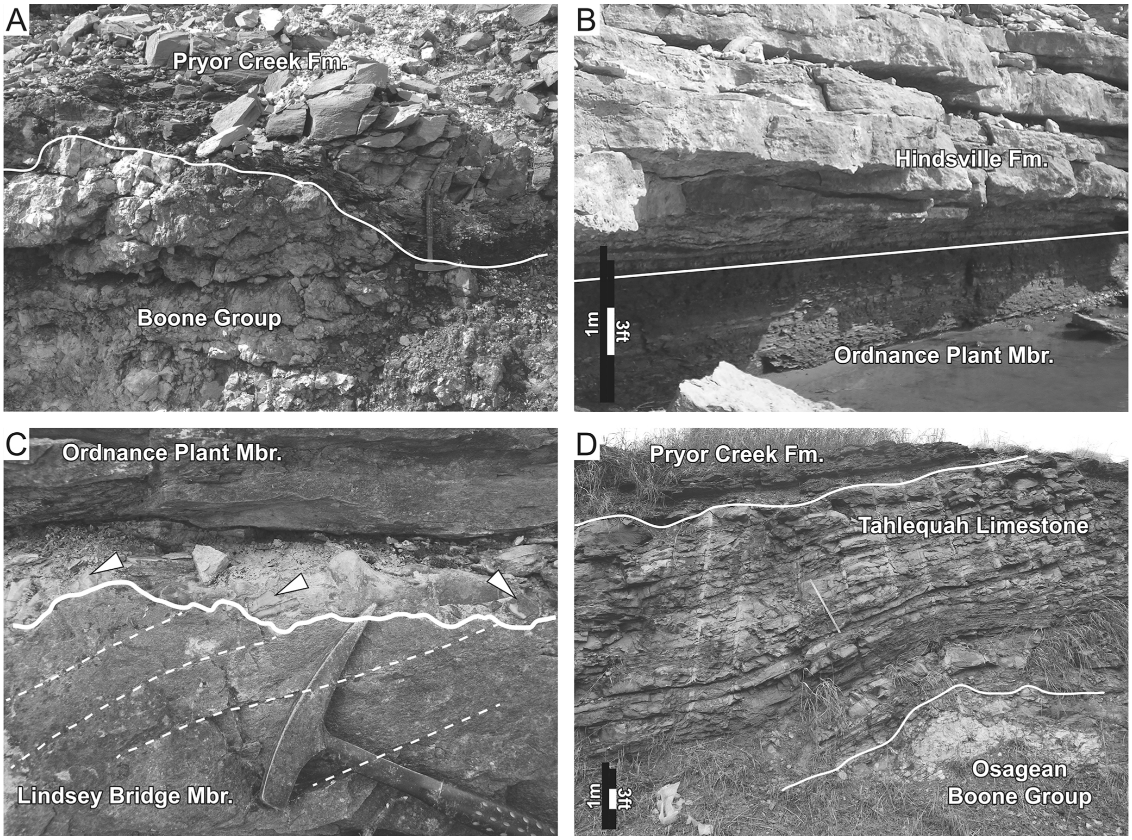


Figure 4. (A) Sub-Mayes unconformity at the Pryor Creek type locality (location 15). Bottom part of south quarry high-wall type section from Figure 3. (B) Conformable Ordnance Plant-Hindsville contact at location 12. (C) Unconformable Lindsey Bridge-Ordnance Plant contact. White arrows indicating chert clasts derived from Boone Group. (D) Tahlequah principal reference locality (location 3). Unconformable contacts between the Osagean Boone Group and Pryor Creek Formation. Rock hammer is 12 inches (30.5 cm) long.

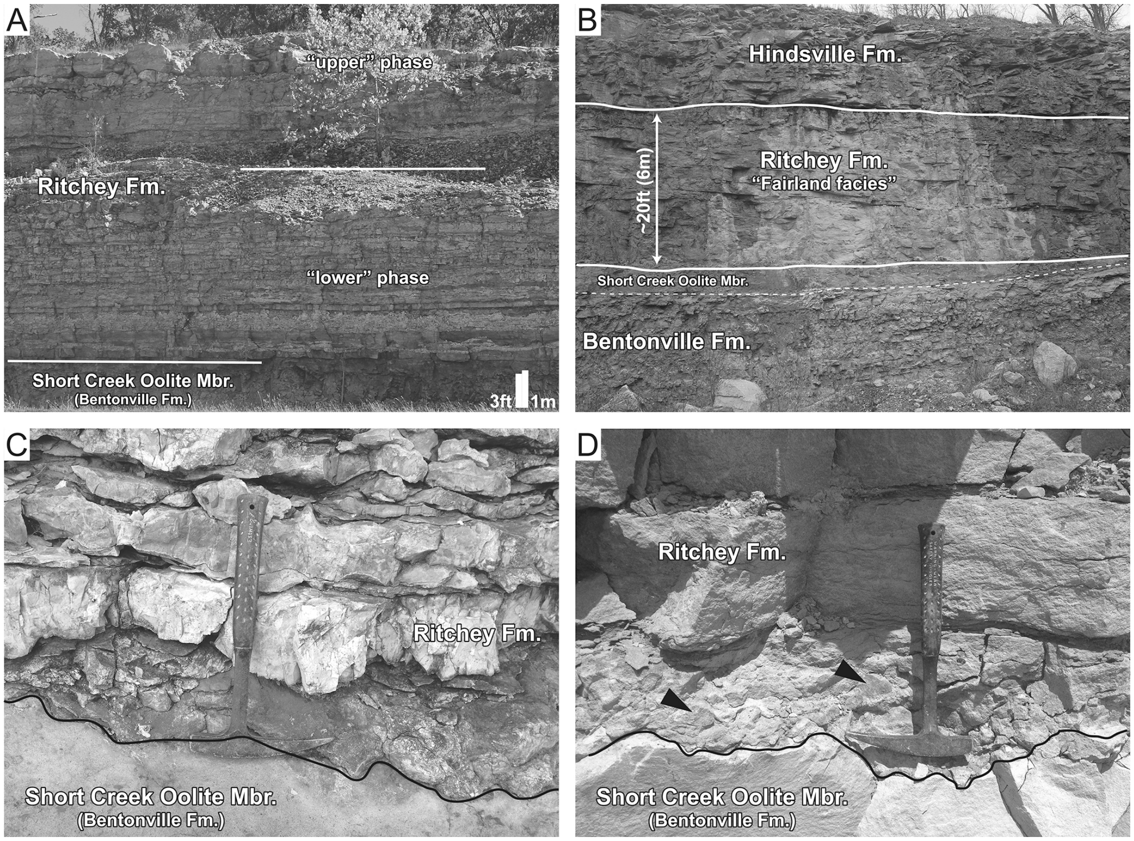


Figure 5. (A) Lower and upper phases of the Ritchey Formation at location 32 (Newton County, Missouri). (B) "Fairland facies" of the Ritchey Formation at location. (C) Sub-Ritchey unconformity at location 24. (D) Sub-Ritchey unconformity at location 22 displaying irregular surface and inclusion of clasts of Short Creek Oolite (black arrows) within the basal Ritchey Formation. Rock hammer is 12 inches (30.5 cm) long.

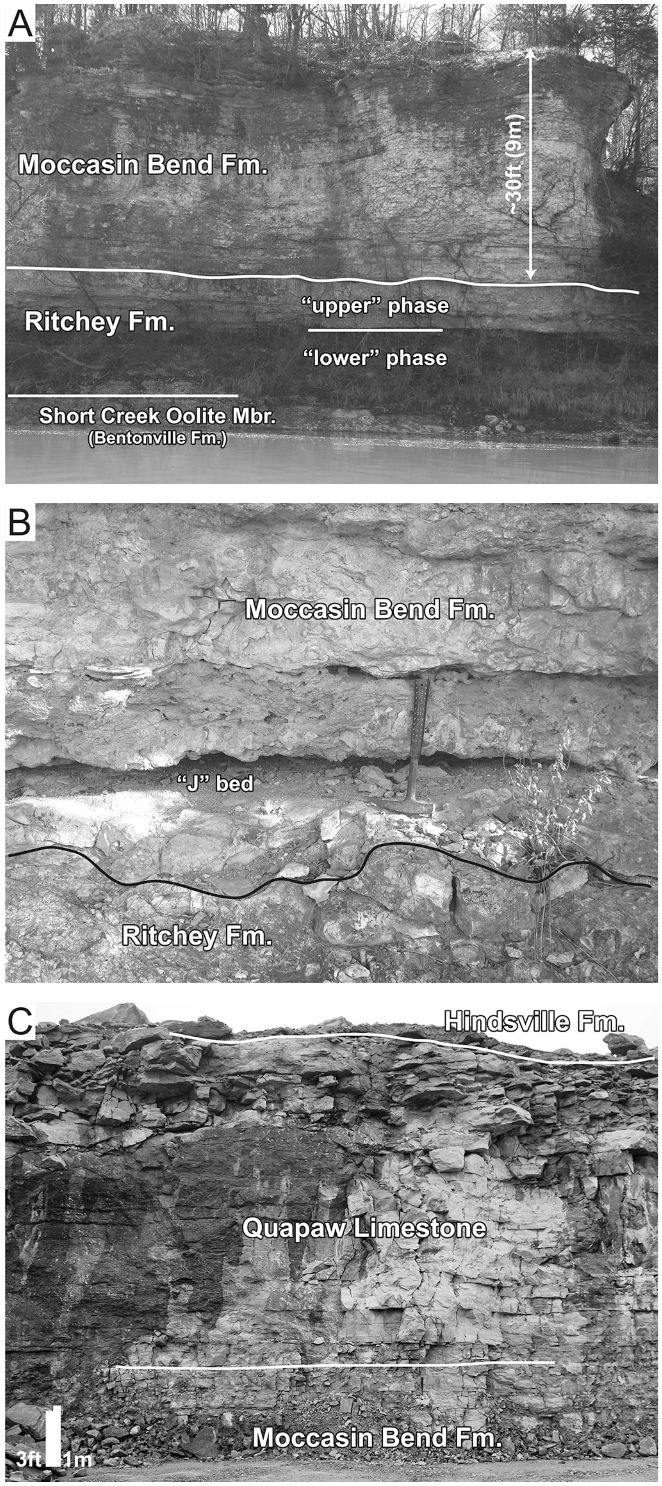


Figure 6. (A) One of many exposures along the bluffs of the Spring River in Ottawa County, Oklahoma which make up the Moccasin Bend type locality (location 25). (B) Sub-Moccasin Bend unconformity at location 24, the informal glauconite-rich "J" bed is interpreted as representing post-unconformity deposition at the base of the Moccasin Bend Formation. (C) Quapaw Limestone principal reference locality (location 27). Rock hammer is 12 inches (30.5 cm) long.

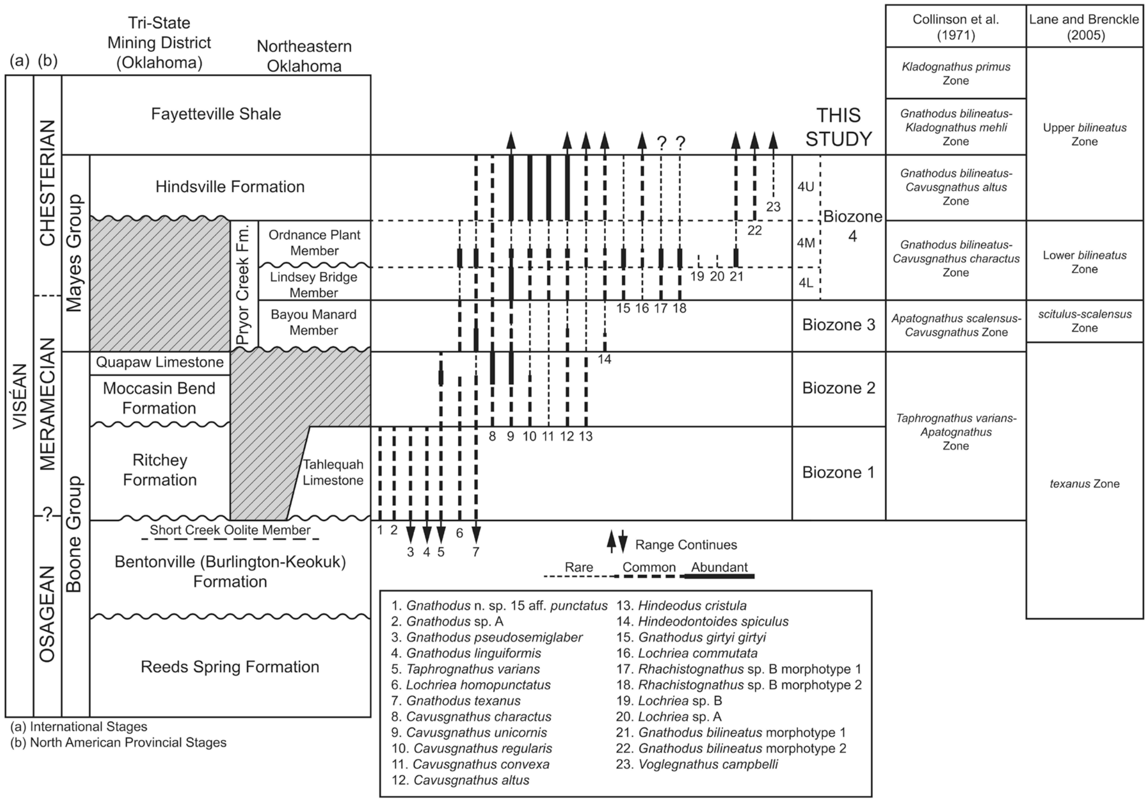


Figure 7. Observed conodont ranges and proposed informal conodont zonation for the upper Boone Group and Mayes Group highlighting the temporal relationships between strata in the northeastern Oklahoma and correlation with established conodont zonation schemes.

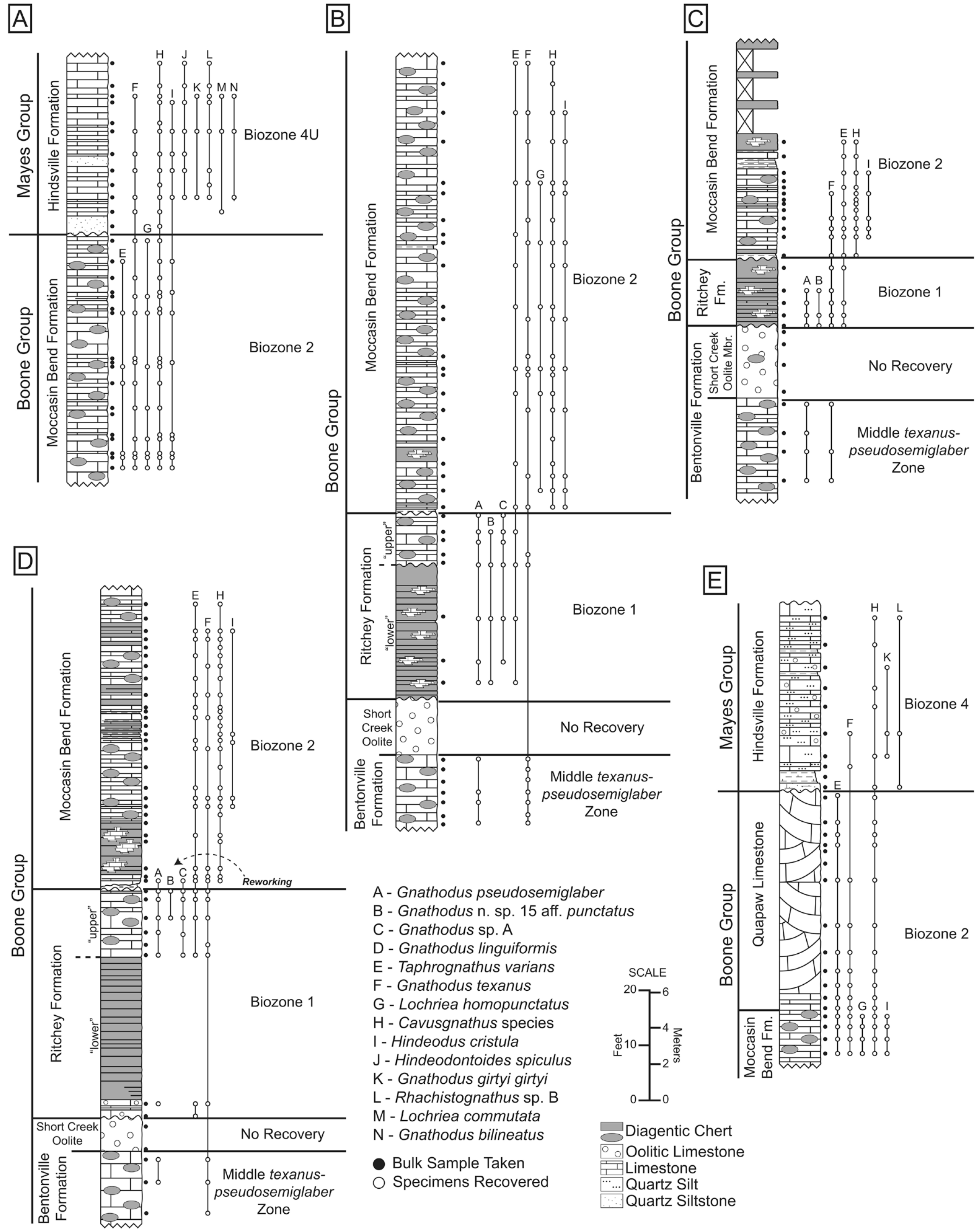


Figure 8. Conodont occurrences and ranges from selected locations in the Tri-State Mining District illustrating the definitions of Biozone 1 and Biozone 2. Included is the Middle *texanus-pseudosemiglabe*r Zone of Boardman et al. (2013). (A) location 21; (B) location 25; (C) location 24; (D) location 28; and (E) location 27.

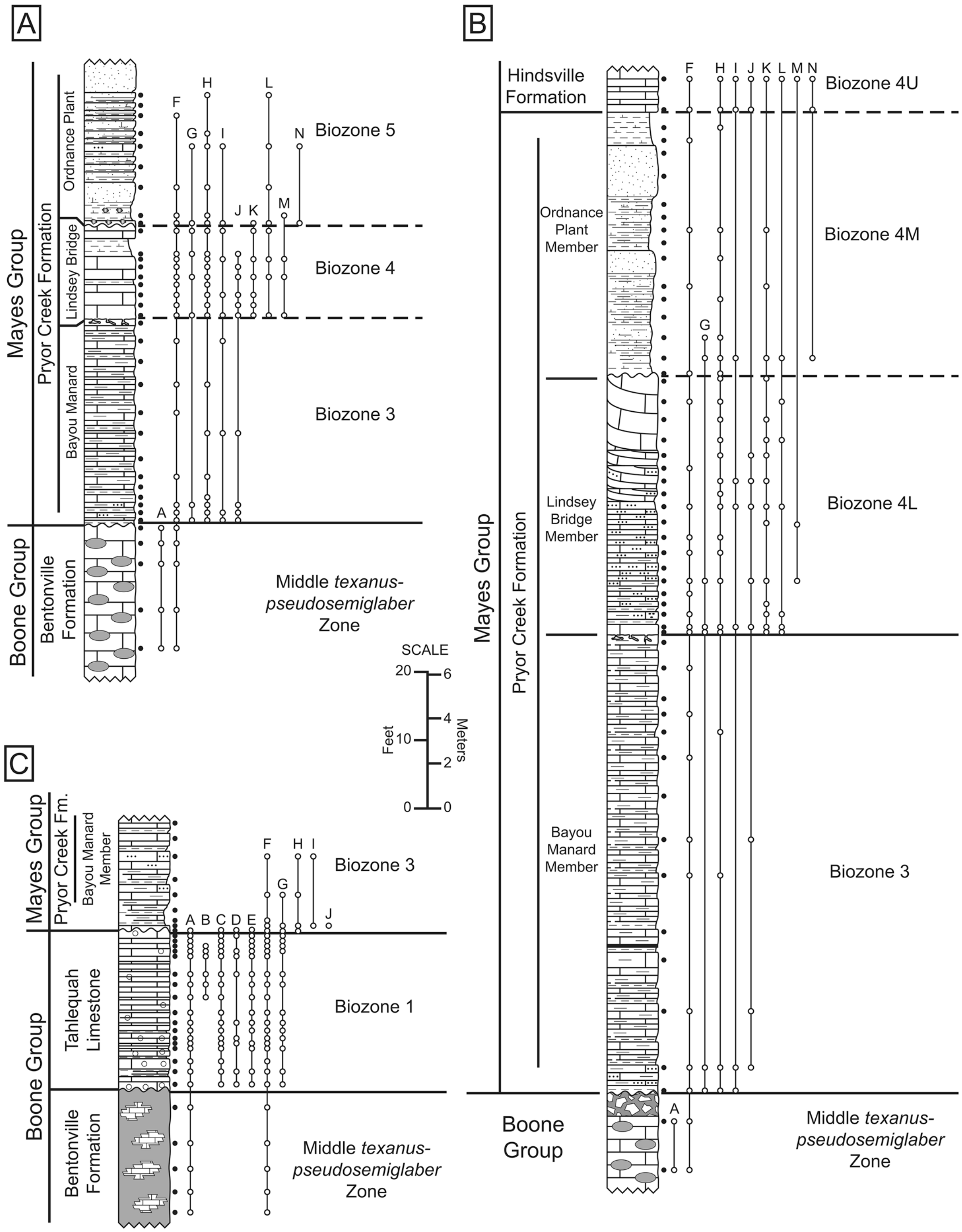


Figure 9. Conodont occurrences and ranges from selected locations in northeastern Oklahoma illustrating the definition of biozones within the Mayes Group and well as the separation between the Pryor Creek Formation and Tahlequah Limestone (Biozone 1). (A) location 13; (B) location 14; and (C) location 3.

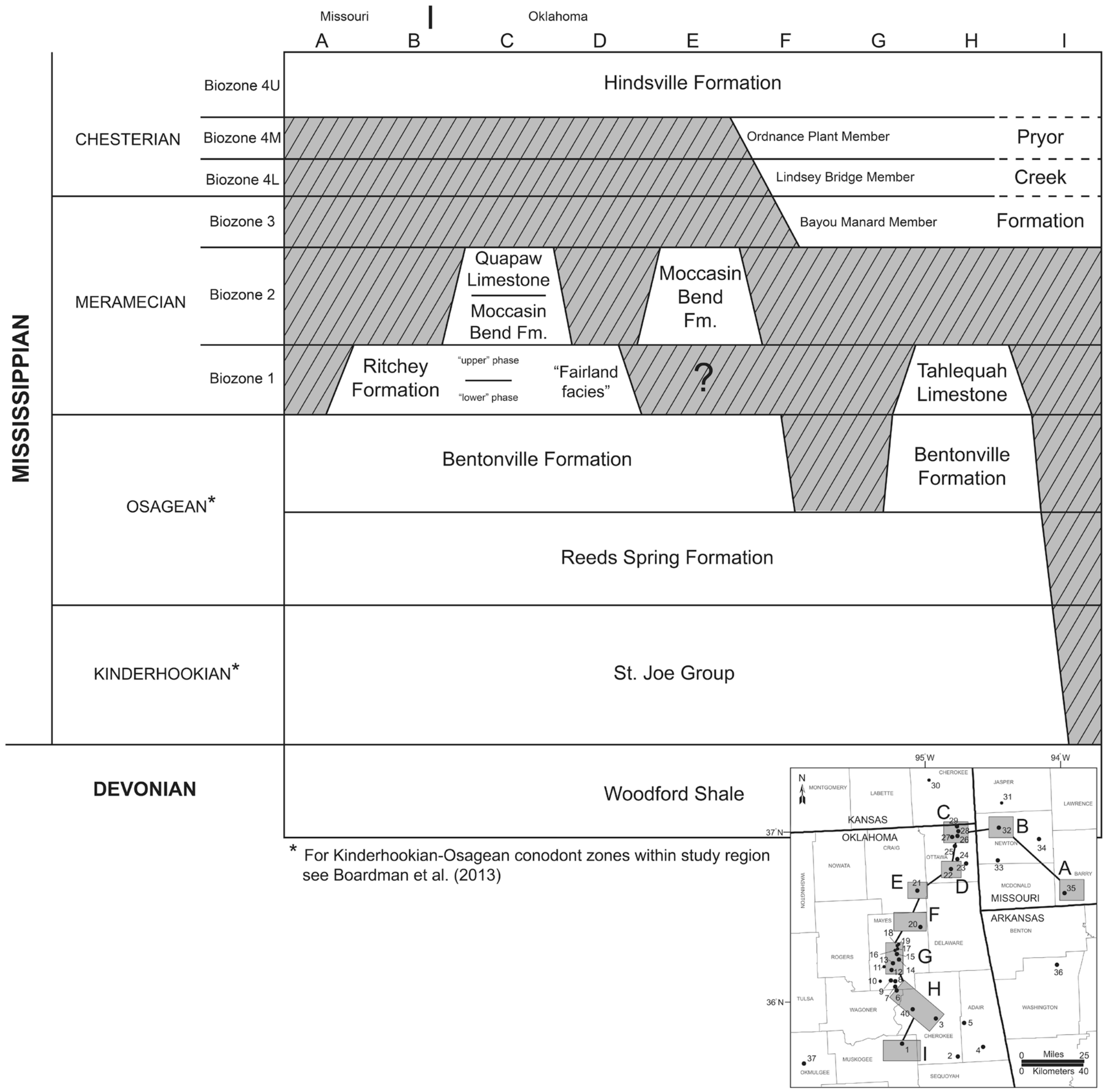


Figure 10. Generalized regional cross-section depicting the chronostratigraphic relationships within the study interval from the Tri-State Mining District (A to E) into the northeastern Oklahoma (E to I), as shown in the inset map.

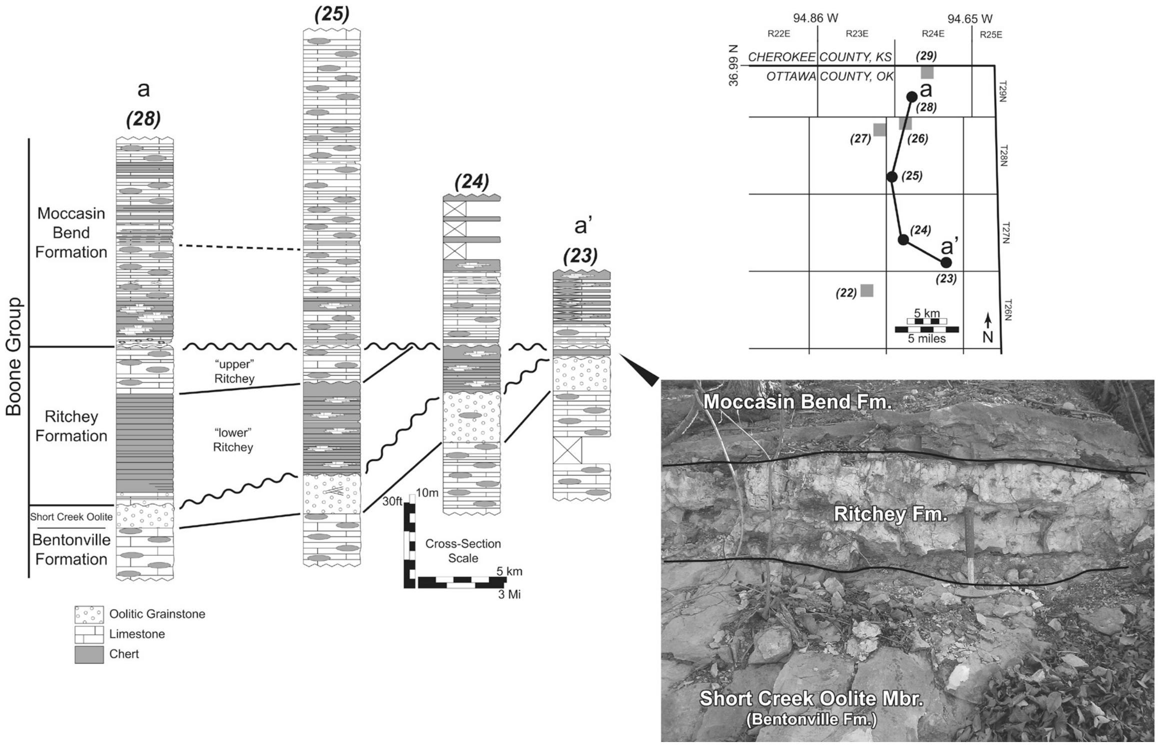


Figure 11. Cross-section (a-a’) illustrating truncation of Ritchey Formation by unconformity below Moccasin Bend Formation in Ottawa County, Oklahoma, Tri-State Mining District. Photograph depicts stratigraphic relationships at location 23.

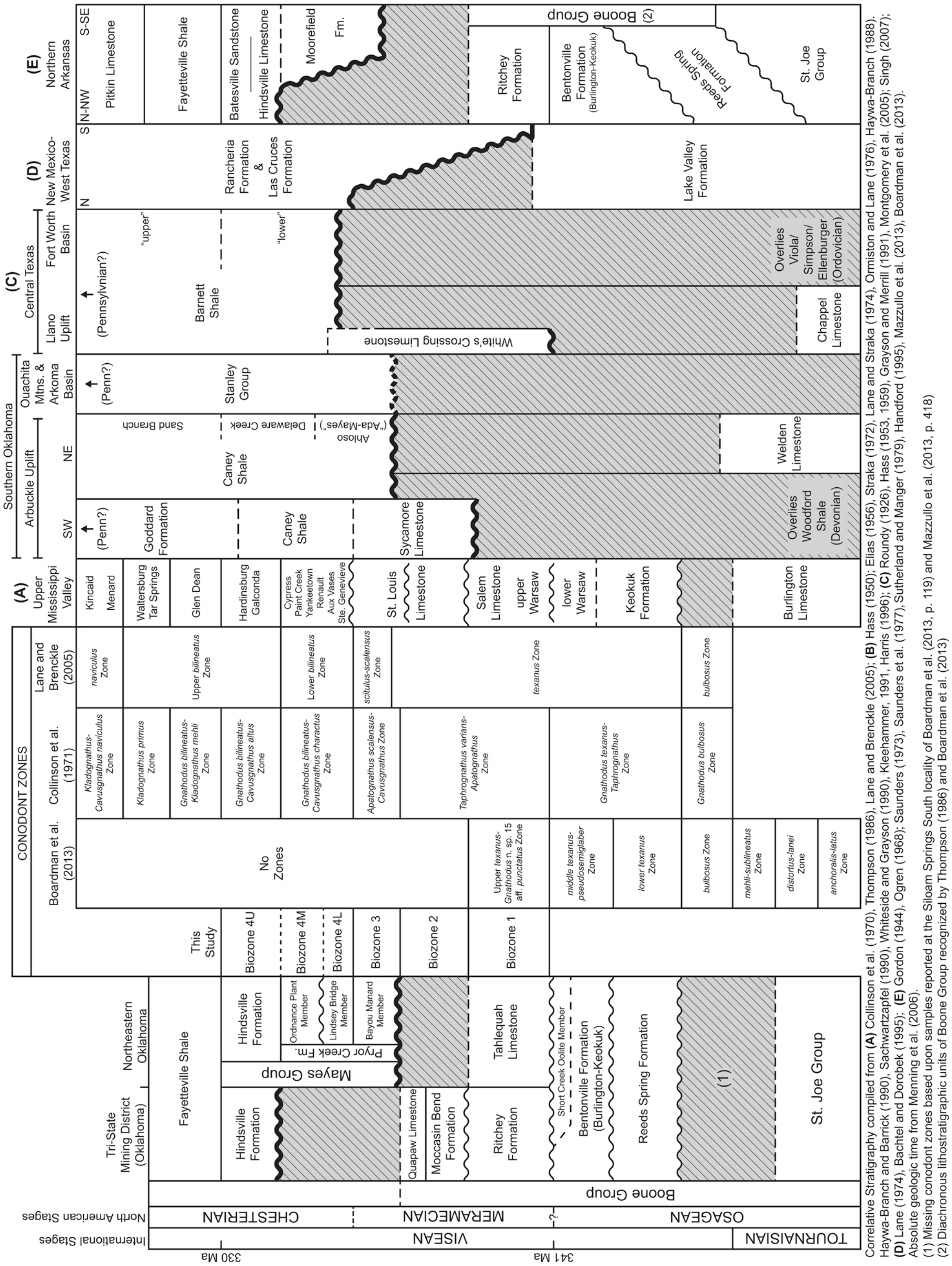


Figure 12. Chart illustrating the conodont-based interpreted interregional correlations between Osagean through Chesterian strata of the study area, a generalized section of the Upper Mississippi River Valley, and selected areas within the southern mid-continent.

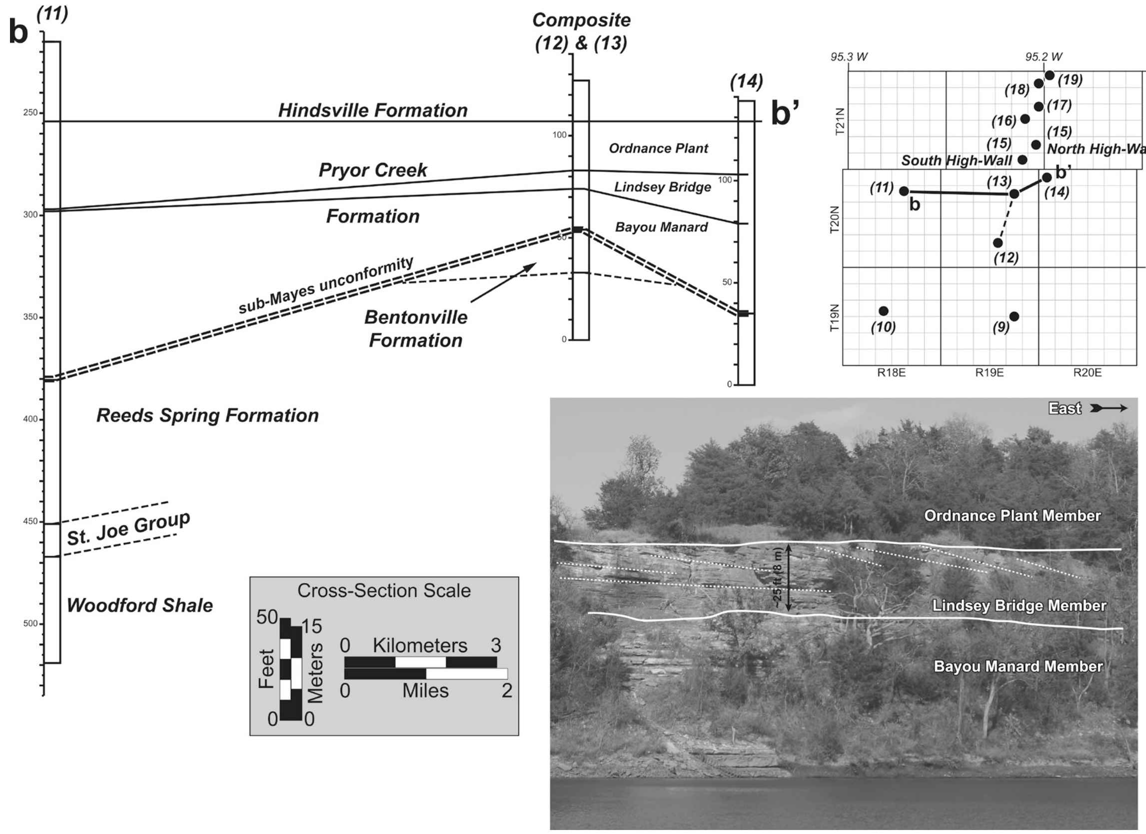


Figure 13. Northeastward prograding limestone beds (dashed lines) in the Lindsey Bridge Member at location 14 and associated cross-section illustrating thinning of the Pryor Creek Formation across a paleotopographic high consisting of remnant Bentonville Formation strata.

CONODONT PLATE 1

(Scale bar in lower right hand corner is 500 microns.)

All specimens held at the Paleontology Repository, Department of Earth and Environmental Sciences, University of Iowa.

Figure A – *Gnathodus* sp. A; Tahlequah Limestone, location 3. (SUI 141545)

Figure B – *Gnathodus pseudosemiglaber* Thompson and Fellows (1970); Tahlequah Limestone, location 3. (SUI 141191)

Figure C – *Gnathodus* n. sp. 15 aff. *punctatus* (Boardman et al., 2013); Ritchey Formation, location 22. (SUI 141683)

Figure D – *Taphrognathus varians* Branson and Mehl (1941b); Quapaw Limestone, location 27. (SUI 141448)

Figure E – *Gnathodus girtyi girtyi* (Hass, 1953); Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141350)

Figure F – *Hindeodus cristula* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141631)

Figure G – *Hindeodontoides spiculus* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141633)

Figure H – *Cavusgnathus unicornis* (Youngquist and Miller, 1949); Hindsville Formation, location 12. (SUI 141295)

Figures I through L – *Rhachistognathus* sp. B

I – Hindsville Formation, Boone County, Arkansas (Not included in Figure 1) (SUI 141307)

J – Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141202)

K – Lindsey Bridge Member, Pryor Creek Formation, location 13. (SUI 141261)

L – Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141335)

Figure M – *Lochriea homopunctatus* (Ziegler, 1960); Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141206)

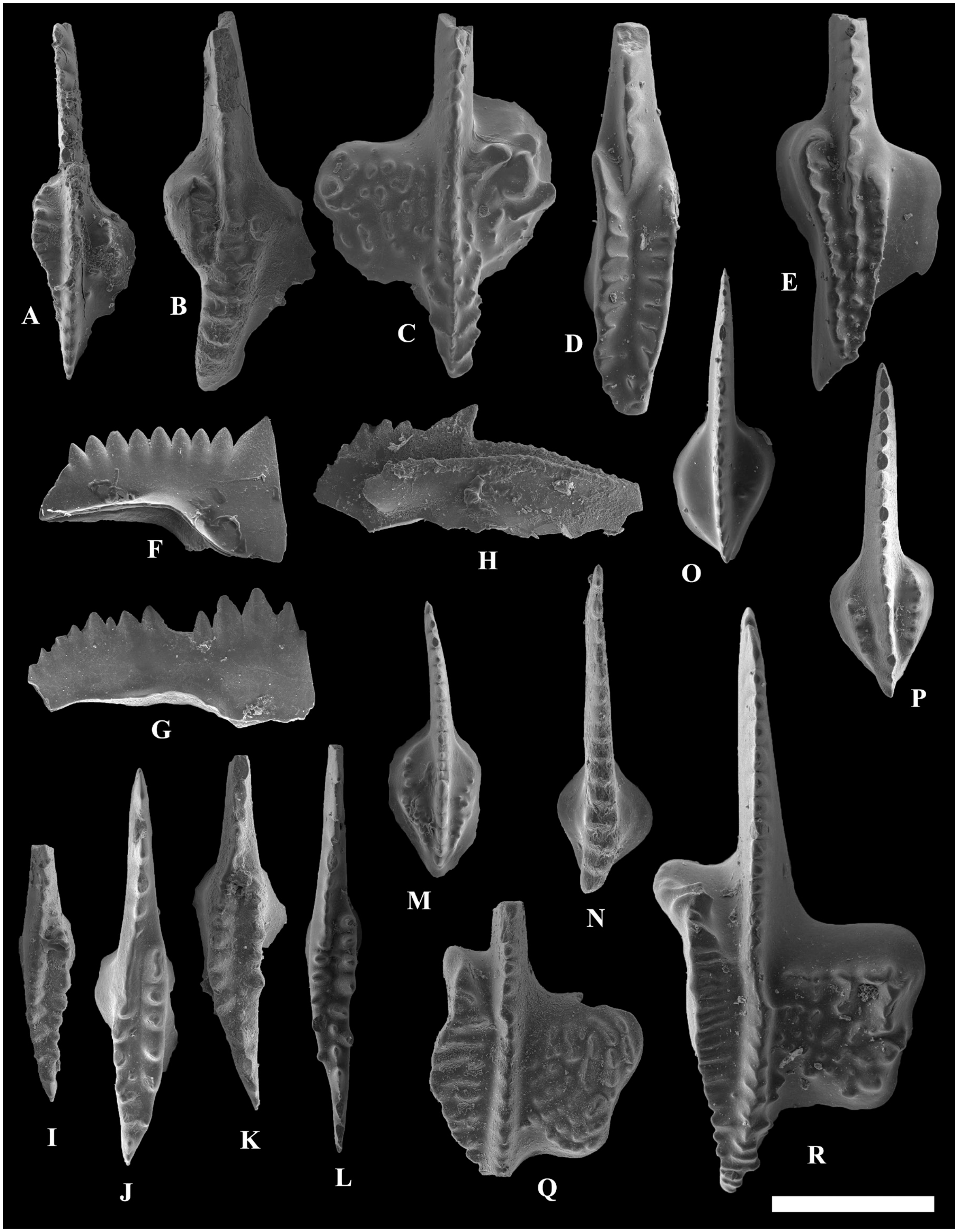
Figure N – *Lochriea commutata* (Branson and Mehl, 1941a); Hindsville Formation, location 36. (SUI 141317)

Figure O – *Lochriea* sp. A; Ordnance Plant Member, Pryor Creek Formation, Location 9. (SUI 141377)

Figure P – *Lochriea* sp. B.; Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141207)

Figure Q – *Gnathodus bilineatus* (Roundy, 1926), morphotype 2; Hindsville Formation, location 36. (SUI 141311)

Figure R – *Gnathodus bilineatus* (Roundy, 1926), morphotype 1; Ordnance Plant Member, Pryor Creek Formation, location 9. (SUI 141331)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CHAPTER IV

DEPOSITIONAL CYCLICITY WITHIN THE MAYES GROUP (MERAMECIAN-CHESTERIAN) ALONG THE WESTERN EDGE OF THE MISSISSIPPIAN OUTCROP BELT IN NORTHEASTERN OKLAHOMA

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ABSTRACT

Multiple orders of depositional cyclicity in the Mayes Group of northeastern Oklahoma are delineated by refined depositional facies associations and stratigraphic surfaces. Facies associations include deep subtidal facies, shallow subtidal facies (including distal and proximal subfacies), carbonate shoal facies, and shoal crest facies. The Mayes Group records a primary transgressive-regressive depositional cycle bounded below by a major unconformity (sub-Mayes unconformity) and above by an important provincial conodont biostratigraphic boundary and widespread flooding surface at the base of the Fayetteville Shale. Within the Mayes Group, two secondary transgressive-regressive depositional cycles are separated by an interpreted unconformity. The lower Mayes cycle comprises the Bayou Manard and Lindsey Bridge members of the Pryor Creek Formation, whereas the Ordnance Plant Member is grouped with the Hindsville Formation in the upper Mayes cycle. Present in both the lower and upper Mayes cycles are high-frequency shallowing-upward cycles bounded by flooding surfaces. Evaluating the

distribution of facies and stratigraphic surfaces within a framework of multiple orders of depositional cyclicity is essential to interpreting the geologic evolution of the southern mid-continent during the Meramecian and Chesterian, and impacts oil and gas production by improving our understanding of reservoir compartmentalization.

INTRODUCTION

The Mayes Group, consisting of the Pryor Creek Formation and overlying Hindsville Formation, is exposed in outcrops and was penetrated in shallow subsurface cores in northeastern Oklahoma, including the Mayes Group type area in central Mayes County, where a collection of complete or nearly stratigraphic sections is easily accessible (Figure 1). Because of their position along the western edge of the Mississippian outcrop belt, these sections are relevant to potential studies concerning hydrocarbon-bearing time-equivalent strata in the subsurface of Oklahoma. Additional surface localities and subsurface core were examined in Missouri, Kansas, and Arkansas because they represent potential points of reference for understanding the Hindsville Formation, which is more widely distributed that is the Pryor Creek Formation.

The clear majority of previous work concerning or referencing the Mayes Group focused on lithostratigraphic nomenclature, surface mapping, and subsurface correlation (e.g. Snider, 1915; Buchanan, 1927; Brant, 1934, 1941; Selk, 1949; Bollman, 1950; Huffman and Barker, 1950; Douglass, 1952; Degraffenreid, 1953; Slocum, 1955; Huffman, 1958; Starke, 1961; Krueger, 1964; Huffman et al., 1966; Selk, 1973; Turmelle, 1983). Although as many as two transgressive-regressive depositional cycles have been interpreted in the Mayes Group, internal variations in lithology were simply attributed to facies interfingering with minimal discussion concerning organization of facies beyond that of an overall shallowing-upward succession (Huffman, 1958; Turmelle, 1982).

During the Mississippian, northeastern Oklahoma was located approximately 15 degrees south of the equator along a broad carbonate platform, interpreted as a shelf (Lane and De

Keyser, 1980; Gutschick and Sandberg, 1983) and ramp to distally-steepened ramp (Handford, 1986; Handford, 1995; Mazzullo et al., 2013) that extended across the mid-continent and into the southwestern United States. Within this setting, Mayes Group facies distribution and depositional cyclicity were influenced by eustatic sea-level changes associated with the onset of Late Paleozoic glaciation (Mii et al., 1999; Smith and Read, 2000) and early phases of Ouachita tectonism (Huffman, 1958; Bradley and Leach, 2002; Houseknecht et al., 2014; Mazzullo et al., this volume).

Recognition of depositional cycles in the type Mayes Group serves as the foundation upon which more comprehensive sequence stratigraphic models can be constructed. These models are critical to future evaluation of the Mississippian petroleum system, including predicting potential reservoir compartmentalization. Identification of Mayes Group depositional cycles relies on an improved understanding of the distribution of, and relationships between, an expanded suite of depositional facies and revised stratigraphic surfaces of local to regional extent.

Stratigraphic surfaces and facies assemblages provide the basis for recognizing a hierarchy of depositional facies in the Mayes Group. Additionally, the proposed depositional cycles and facies relationships explain in a predictable manner the lithostratigraphic variations evident in the Mayes Group.

METHODOLOGY

A total of 27 surface and shallow subsurface sections were examined in northeastern Oklahoma, with an emphasis placed on central Mayes County where the Mayes Group type area) contains nine closely-spaced and nearly complete to complete stratigraphic sections (locations 11-19). Surface locations within the outcrop belt, away from the type area, are typically less complete and more widely separated. To the west-southwest of the type area, three additional subsurface cores were examined, two in Mayes County and one in Okmulgee County. These cores supplement the sections within the type area and strengthen surface-to-subsurface correlations.

From the sections examined, more than 300 slabbed and polished hand samples and 200 standard thin-sections were prepared to complement field and core descriptions. Hand samples and thin sections from outcrops and cores were described using the carbonate classification of Dunham (1962) and Embry and Klovan (1971). Observations from outcrops and subsurface cores were augmented with descriptions of sections reported in Slocum (1955), Huffman (1958), and Turmelle (1982).

Conodonts recovered from bulk samples taken from outcrops and some shallow subsurface core are used in this study to define the relative age constraints of the Mayes Group, as well as to ascertain any correlation between depositional cyclicity and faunal trends (see Godwin et al., this volume).

RESULTS

Lithostratigraphy

The Mayes Group includes the Pryor Creek Formation and overlying Hindsville Formation (Godwin et al., this volume) (Figure 2). In ascending order, the Pryor Creek Formation is divided into the argillaceous limestone of the Bayou Manard Member, fine to coarse bioclastic limestone of the Lindsey Bridge Member, and calcareous siltstone and shale of the Ordnance Plant Member. The Bayou Manard Member is uppermost Meramecian in age, whereas the Lindsey Bridge Member, Ordnance Plant Member, and overlying Hindsville Formation are Early to Middle Chesterian (Thompson, 1972; Lane and Brenckle, 2005; Godwin et al., this volume). The Hindsville Formation generally consists of fine to coarse-grained bioclastic and oolitic limestone, but also includes lime mudstone, calcareous siltstone, and shale.

The base of the Mayes Group is recognized as a regionally-extensive unconformity (Cline, 1934; Laudon, 1948; Huffman, 1958). Where the Pryor Creek Formation is present, this unconformity coincides with the base of the Bayou Manard Member and separates it from underlying strata ranging in age from Ordovician through Early Meramecian (Figure 3) (Godwin et al., this volume). Where the Pryor Creek Formation is absent, the Hindsville Formation rests unconformably on pre-Mayes strata, typically units of the Boone Group (Osagean-Meramecian). Similar unconformities occur below the Caney Shale and Sycamore Limestone of southern Oklahoma, the Moorefield Formation or Hindsville Formation of northern Arkansas, and the Barnett Shale of Texas (Singh, 2007; Boardman et al., 2012). The unconformity surface is characterized by small to large-scale paleotopographic relief (Figure 3) that influenced Mayes Group deposition. Within the study area, the Bayou Manard and Lindsey Bridge members were most affected by paleotopographic relief along the unconformity and display greater variations in thickness and facies distribution. In contrast, the Ordnance Plant Member and the Hindsville Formation display more consistent thickness and predictable facies trends.

The contact separating the Bayou Manard and Lindsey Bridge members is commonly sharp and characterized by unlined burrows in the uppermost bed of the Bayou Manard Member that were passively filled by sediment of the basal Lindsey Bridge Member (Figure 4). Huffman (1958) noted these features, separately interpreting them as load structures in one instance and as worm borings in another, and described the contact as conformable. Evidence, from outcrops at locations 13, 14, and 15 indicate a period of non-deposition and submarine erosion along the contact, including truncation of the uppermost beds of the Bayou Manard Member and inclusion of subrounded to rounded clasts of Bayou Manard lime mudstone in the basal Lindsey Bridge Member.

The contact between the Lindsey Bridge Member and the Ordnance Plant Member shows evidence of erosional truncation of the Lindsey Bridge in outcrop at locations 13 and 15, as well as in the cores from locations 16, 17, and 18. Elsewhere in central Mayes County, the contact is characterized by an irregular and mineralized (phosphate, iron-oxide) surface (Figure 5A and 5B) with clasts of the Lindsey Bridge Member incorporated in the basal beds of the Ordnance Plant

Member (Figure 5C). At location 13, large (> 2.5 cm) clasts of Osagean Boone Group strata, including apparent clasts of cherty limestone of the Bentonville Formation and oolitic limestone of the Short Creek Oolite Member, occur where the base of the Ordnance Plant Member where an unconformity separates the Lindsey Bridge and Ordnance Plant members. Away from the central Mayes County, an unconformity was also interpreted between these two members at location 4 in Adair County, Oklahoma.

The boundary between the Ordnance Plant Member and overlying Hindsville Formation appears conformable and is commonly marked by the contact between silty shale or shaly siltstone of the upper Ordnance Plant with dark gray-black shale or silty coarse-grained bioclastic packstone-wackestone to floatstone-rudstone of the Hindsville Formation (Figure 6).

The contact between the Hindsville Formation and the Fayetteville Shale is a widespread flooding surface which coincides with the boundary between the *Gnathodus bilineatus-Cavusgnathus altus* and overlying *Gnathodus bilineatus-Kladognathus mehli* conodont zones of Collinson et al. (1971) (Thompson, 1972). In northern Arkansas, the contact was interpreted as diachronous based on ammonoid fauna (Saunders et al., 1977; Handford, 1995).

Thickness and Distribution of the Mayes Group

In outcrop, the Pryor Creek Formation is limited to northeastern Oklahoma, excluding the Tri-State Mining District in the far northeastern corner, and is thickest in central Mayes County where it reaches 95.8 feet (29 m) at location 14 (Figure 7). From there, the Pryor Creek Formation thins rapidly to the north and east, eventually pinching out in Craig and Delaware counties (Huffman, 1958). In the southeastern part of the outcrop area, in Cherokee and Adair counties, the Pryor Creek Formation also thins and pinches-out across a regional paleotopographic high, herein termed the Adair-Cherokee high, (Figure 7). Where the Pryor Creek Formation is absent, the Hindsville Formation rests on pre-Mayes strata. To the west of the outcrop area, the Mayes Group dips into the subsurface and the Pryor Creek Formation continues thickening. It is 127 feet (39 m) thick in core M-207 (location 11), 229 feet (70 m) in core M-211 (location 10), and 213 feet (65 m) in the Baker Hughes BH-1 core (location 27). In the subsurface of Oklahoma, the Mayes Group and more specifically the Pryor Creek Formation has been historically known by several informal names including, but not limited to, the "subsurface Mayes", "Seminole Mayes", and "Mississippi black limestone." The correlation of the Mayes Group with the "subsurface Mayes" has a long, and somewhat contentious history. Cram (1930), Brant (1934, 1941, 1957), and Selk (1949) considered the "subsurface Mayes" to be a downdip facies equivalent of Osagean or Kinderhookian strata to the north and east. In contrast, Aurin et al. (1921), Buchanan (1927), Cline (1934), Huffman and Barker (1950), and Huffman (1958) considered these subsurface strata Meramecian-Chesterian and equivalent to the Mayes Group of the outcrop area.

The Hindsville Formation is between 25 to 45 feet (7.5 to 14.5 m) thick and present throughout northeastern Oklahoma, including the Tri-State Mining District, southwestern Missouri, and northern Arkansas. In northeastern Oklahoma, it thins in the southern part of the study area within Muskogee and Okmulgee counties. Where the Hindsville Formation is absent, the Fayetteville Shale rest on the Pryor Creek Formation.

Depositional Facies Associations

The type Mayes Group consists of four broadly-defined depositional facies associations: deep/restricted subtidal, shallow subtidal, carbonate shoal, and shoal crest. Boundaries between these facies associations are commonly gradational and their distribution is interpreted within an inferred carbonate ramp setting following Burchette and Wright (1992) (Figure 8). Additional depositional facies associations are recognized, but they are volumetrically insignificant. Although the precise lithologic expression of each depositional facies, when present, varies between lithostratigraphic units, the defining character of each facies is consistent in terms of their overall depositional energy and inferred bathymetric position. The most notable difference between lithofacies within a defined facies association is the ratio between the carbonate (lime mud and allochems) and siliciclastic (terrigenous silt and clay) components. Representative lithofacies in the Bayou Manard Member, Lindsey Bridge Member, and Hindsville Formation tend to be carbonate-dominated, with lesser amounts of quartz silt and terrigenous clay. Lithofacies of the Ordnance Plant Member are rich in silt and clay.

Deep/Restricted Subtidal Facies Association

The deep/restricted subtidal facies association occurs throughout the Mayes Group and represents deposition in low-energy, open marine to partially-restricted conditions below storm wave base in an outer ramp position (Burchette and Wright, 1992) (Figure 9). Lithofacies included in this association are typically dark in color, terrigenous clay or lime mud-rich, and very thin to medium-bedded. Deep subtidal facies are often horizontally laminated (occasional low-angle cross-laminations) with distinct burrows including *Planolites*, *Chondrites*, and *Zoophycos*. Some lime mudstone-wackestone beds are pervasively bioturbated (fabric-destructive) and therefore appear massive, although faint remnant laminations and distinct horizontal burrows and bedding-plane traces were observed Quartz silt, silt-sized bioclasts and peloids (microbioclasts), and larger disarticulated open marine fauna are rare to common and may represent down-dip storm transport (Handford, 1986).

Shallow Subtidal Facies Association

The shallow subtidal facies association represents deposition between storm wave base and fair-weather wave base in what is considered the middle ramp (Burchette and Wright, 1992) (Figure 10). Lithofacies in this facies association are storm-influenced and represent a wide-spectrum of depositional conditions from low-energy in more distal positions through moderate to high-energy in more proximal positions (Burchette and Wright, 1992). Distally, just above storm wave base, shallow subtidal facies transition to deep subtidal facies. These facies are characteristically very thin to medium-bedded, brownish-gray to dark brownish-gray, lime mud/terrigenous clay-rich, and burrowed to pervasively (fabric-destructive) bioturbated. Internal horizontal to low-angle cross-laminations occur, but are rare. In more proximal positions, closer to fair-weather wave base, shallow subtidal facies are gradational with carbonate shoal facies, and are thus marked by an increase in the percentage of fine to coarse-grained bioclasts, and decrease in bioturbation, quartz silt, lime mud, and terrigenous clay. Discrete burrows in the shallow subtidal facies association include *Skolithos* and *Planolites*. Although symmetrical ripples are present locally in the Ordnance Plant Member, no evidence of periodic subaerial exposure is apparent.

Carbonate Shoal Facies Association

This facies association is characterized by high-energy deposition in open-marine waters above fair-weather wave base where sediments are well-washed, grain-supported, and cross-stratified. Carbonate shoal facies are quite diverse, but generally consist of bioclastic-lithoclastic packstone-grainstone and crinoidal-bryozoan packstone-grainstone (Figure 11). Allochems include typical open-marine fauna, (often with micritic coatings), ooids, and peloids. Allochtonous lithoclasts are common in the Lindsey Bridge Member (Figure 11A and 11C), and include sand to cobble-sized chert clasts derived from erosion of the Boone Group and locally abundant pebble-sized lime mudstone clasts derived from the top of the Bayou Manard Member. Chert clasts are also common in carbonate shoal facies at the base of the Hindsville Formation where it rests on the Boone Group, including location 21 in Craig County, Oklahoma, location 22 in Ottawa County, Oklahoma, and location 25 in Barry County, Missouri.

Shoal Crest Facies Association

Although closely associated with the carbonate shoal facies association, the shoal crest facies association occurs only within the Hindsville Formation and is characterized by a predominance of fine to coarse-grained ooids and micrite-coated bioclasts (immature ooids) and internal cross-stratification (Table 1) (Figure 11F).

Backshoal Intertidal Facies Association

Backshoal intertidal facies represent low-energy deposition landward of an active carbonate shoal and only recognized in the Hindsville Formation in the Tri-State Mining District during this investigation. At location 22 in Ottawa County, Oklahoma, the Hindsville Formation contains features indicative of an intertidal setting, including mudcracks, symmetrical ripples, and mud rip-ups. At location 23 in Ottawa County, the Hindsville Formation consists of thin-bedded, silty to sandy, very fine to fine-grained oolitic-bioclastic packstone-grainstone with mudcracks in more mud-rich rocks.

Stratigraphic Surfaces

Important regionally-extensive stratigraphic surfaces used to interpret Mayes Group depositional cyclicity include the sub-Mayes unconformity, Bayou Manard-Lindsey Bridge contact, sub-Ordnance Plant unconformity, Ordnance Plant-Hindsville contact, and Hindsville-Fayetteville contact. Important secondary stratigraphic surfaces include flooding surfaces and burrowed surfaces. Flooding surfaces separate relatively deeper-water facies from underlying shallower-water facies and are characterized by one or more of the following: glauconite, phosphate, and skeletal lags. Facies variation across the flooding surface can be subtle and identification predicated on the occurrence of grain-rich lags. Some flooding surfaces also coincide with unconformities. Burrowed surfaces are likewise important to the interpretation of depositional cyclicity because they are often well-developed at the transition between transgressive and regressive deposition. These surfaces contrast with more commonly occurring smaller, but distinct burrows, trace fossils, and texture-destructive bioturbation in that burrowed surfaces occur along bed boundaries separating relatively deeper-water facies below from shallower-water facies above. The Bayou Manard-Lindsey Bridge contact is an example of one such burrowed surface, but unlike others it is regionally-extensive. Burrowed surfaces also occur in the Ordnance Plant Member and Hindsville Formation.

Interpreted Depositional Cycles

Based on the distribution of depositional facies associations and stratigraphic surfaces, multiple orders of depositional cyclicity are recognized within the Mayes Group (Figure 12). These cycles are traced with variable confidence in central Mayes County (Figure 13) and into the shallow subsurface (Figure 14). As a whole, the Mayes Group succession records overall shallowing upward, herein referred to as the primary transgressive-regressive depositional cycle. This succession is easily traceable across the type area, as well as throughout much of northeastern Oklahoma and into the shallow subsurface. This primary cycle contains two prominent secondary transgressive-regressive depositional cycles, herein termed the lower Mayes cycle and upper Mayes cycle (Figure 12). Each of these secondary cycles contains higher-frequency depositional cycles, which are interpreted and correlated with less confidence than the secondary transgressive-regressive depositional cycles.

Where both the Pryor Creek and Hindsville formations are present, the overall shallowing upward succession that characterizes the primary transgressive-regressive cycle is easily recognizable throughout central Mayes County and much of northeastern Oklahoma in general, regardless of overall thickness of the Mayes Group. Where the Pryor Creek Formation is present, both the lower and upper Mayes cycles, separated by the sub-Ordnance Plant unconformity, are also recognizable and traceable in central Mayes County and much of northeastern Oklahoma where lithostratigraphic divisions are well defined.

Lower Mayes Cycle

The lower Mayes cycle consists of the Bayou Manard and Lindsey Bridge members of the Pryor Creek Formation and is bounded below by the sub-Mayes unconformity and above by the sub-Ordnance Plant unconformity. The Bayou Manard Member represents initial transgression across the sub-Mayes unconformity within accommodation formed by the apparent removal of Boone Group and older strata. Basal beds of the Bayou Manard Member are siltier than overlying beds and contain abundant glauconite, phosphate, quartz-silt, and silt-sized skeletal debris. In some instances, thin (centimeter-scale) variably cross-laminated, calcareous siltstone beds (shallow subtidal facies) are present at the base of the Bayou Manard Member. These beds represent the initial transgression across the unconformity surface. Overlying Bayou Manard Member strata are typically dominated by lime mudstone-wackestone of the deep subtidal to distal shallow subtidal facies, although proximal shallow subtidal facies are present in northern Mayes County and along the flank of the "Adair-Cherokee high", both of which are associated with overall thinning (and inferred shallowing) of the Pryor Creek Formation. Transition between the transgressive and regressive depositional stages of the lower Mayes cycle coincides with the lithostratigraphic boundary between the Bayou Manard and Lindsey Bridge members. This contact is a burrowed surface interpreted as a marine firmground discontinuity or omission surface characterized by low-diversity *Glossifungites* ichnofacies (MacEachern et al., 1992). The thickness of the lower Mayes cycle (i.e. Bayou Manard and Lindsey Bridge members) varies across the study area. Thus, characteristics of both the transgressive and regressive stages vary, as does the number of interpreted higher-frequency cycles. Where the lower Mayes cycle is less than 30 feet (9 m) thick, the regressive stage consists only of carbonate shoal facies. However, where the lower Mayes cycle is thicker, the regressive stage above the marine firmground discontinuity includes deep subtidal and shallow subtidal facies that grade upward into an upper carbonate shoal facies. In the southern part of the study area and in the subsurface of southwestern Mayes County and Okmulgee County, proximal shallow subtidal and carbonate shoal deposits of the regressive stage Lindsey Bridge Member are thin or absent and replaced by distal shallow subtidal to deep subtidal facies. These more distal facies are lithostratigraphically assigned to either the Bayou Manard Member or Ordnance Plant Member, or simply grouped with them as the undifferentiated Pryor Creek Formation, such as in southern Muskogee County (Huffman, 1958) or in the subsurface cores from locations 10 and 27. In such instances, definitive shallowing upward character is not recognized.

Higher-frequency cycles were not identified with a high level of confidence in surface exposures in which the lower Mayes cycle was less than 30 feet (9m) thick (Figure 13 and location 13 in Figure 14). Higher-frequency cycles are, however, interpreted and correlated with more confidence in thicker Bayou Manard Member sections where flooding surfaces are characterized by subtle lithologic variations (between distal shallow subtidal and deep subtidal facies associations) and thin lag deposits consisting of skeletal debris and phosphate grains (Figure 14). That said, the overall vertical succession in these thicker shallow subsurface sections of the lower Mayes cycle appear to be aggradational in nature following the initial deepening apparent in the basal Bayou Manard Member above the sub-Mayes unconformity. Potential cycle boundaries are also tentatively interpreted in sections of the Bayou Manard Member where the cycle boundary is associated with burrow-nucleated black vitreous chert. At location 14, a 5.5 feet (1.7 m) zone of abundant burrow-nucleated nodules of black vitreous chert is located 12 to 15 feet (3.6 to 4.6 m) above the base of the Bayou Manard Member and separates sections of the deep/restricted subtidal facies association. A similar zone of black vitreous chert was observed in the subsurface core at location 17. The cross-section illustrated in Figure 14 depicts a decrease in the number of identifiable higher-frequency cycles between the expanded sections in the subsurface cores (locations 10 and 11) and thinner sections in surface exposures (locations 13 and 14). In sections in which the lower Mayes cycle is greater than 30 feet (9 m) thick, including locations 14, 15, 17, and 18, the regressive stage (Lindsey Bridge Member) of the lower Mayes cycle is a single high-frequency cycle that shallows upward from deep subtidal facies through carbonate shoal facies (Figure 14). In thinner sections, the Lindsey Bridge Member consists predominantly of carbonate shoal facies. At both location 14 and location 15 (Figure 14), however, the shallowing-upward succession of the regressive stage Lindsey Bridge Member consists of northeastward dipping strata interpreted as prograding foresets associated with paleotopographic highs (Swinchatt, 1967).

Upper Mayes Cycle

The upper Mayes cycle includes the Ordnance Plant Member and overlying Hindsville Formation. This secondary transgressive-regressive cycle is bounded below by the sub-Ordnance Plant unconformity and above by the contact between the Hindsville Formation and Fayetteville Shale (Huffman, 1958; Ogren, 1968). The siltstone and shale-dominated Ordnance Plant Member represents the transgressive stage and the carbonate sand-dominated Hindsville Formation represents the regressive stage.

Two characteristics set the upper Mayes cycle apart from the lower Mayes cycle. First, the upper Mayes cycle displays a greater consistency in overall thickness across the study area, whereas the thickness of lower Mayes cycle is more variable and increases into the subsurface. Second, the upper Mayes cycle consists of conspicuous higher-frequency cycles that are interpreted and correlated with more confidence than those of the lower Mayes cycle. The Ordnance Plant Member consists of higher-frequency cycles (Figure 15) characterized by silty shallow subtidal and shaly deep subtidal facies, with scarce carbonate shoal facies. Higher-frequency cycles in the Ordnance Plant Member are bounded by flooding surfaces with abundant phosphate and skeletal-lag deposits (Figure 16). Stacking of cycles in the Ordnance Plant Member appears to be retrogradational. To the south and west of central Mayes County, deep subtidal facies in the Ordnance Plant Member become more predominant during the transition from proximal to distal ramp settings (Huffman, 1958). The Hindsville Formation contains higher-frequency cycles (Figure 17) dominated by carbonate shoal, shoal crest, and proximal shallow subtidal facies, but locally includes deeper subtidal and distal shallow subtidal facies in parts of central Mayes County and at locations to the south and west. Higher-frequency cycles in the Hindsville Formation are bounded by glauconitic flooding surfaces overlain by silt-rich beds. Contrasting those in the Ordnance Plant Member, stacking of higher-frequency cycles within the Hindsville Formation appears to be progradational. As such, the Hindsville Formation is interpreted as the regressive stage of the upper Mayes cycles. To the south and west of the outcrop area, the lithostratigraphically-defined Hindsville Formation is thin to absent and the Fayetteville Shale appears to rest on shaly deep subtidal facies of the Ordnance Plant Member. In both Ordnance Plant and Hindsville higher-frequency cycles, relatively deeper-water facies (transgressive stage) are separated from relatively shallower-water facies (regressive stage) by a distinct burrowed surface. For the upper Mayes cycle, the transition between the transgressive stage (Ordnance Plant Member) and regressive stage (Hindsville Formation) is placed at the base of the interpreted deepest water facies. This facies is represented locally by either a 2 to 6-inch (5 to 15 cm) section of dark gray to black calcareous to non-calcareous shale (deep subtidal facies) or coarse bioclastic wackestone-packstone to floatstone-rudstone (shallow subtidal facies) at the base of the Hindsville Formation. The interpreted deepest-water facies is overlain, and in some cases removed, by the first definitive carbonate shoal facies of the Hindsville Formation. Burrowed surfaces are present throughout the Hindsville Formation. They occur within higher-frequency cycles separating transgressive stage deposition (relatively lower-energy facies) from overlying regressive stage deposition (relatively higher-energy facies). An intensely burrowed surface is also common near the base of the Hindsville Formation and marks the transition between the transgressive stage deposition (Ordnance Plant Member) and regressive stage deposition (Hindsville Formation) within the upper Mayes cycle.

Conodont faunal abundance and diversity trends correspond to interpreted higher-frequency depositional cycles in Hindsville Formation, with the highest diversity and abundance occurring at the base of the regressive stage of each higher-frequency cycle (Figure 18). In contrast, recoveries from the Ordnance Plant Member, as well as from the lower Mayes cycle, were too poor to establish correspondence to interpreted higher-frequency depositional cycles (Godwin et al., this volume). Also of note in Figure 18, the highest overall conodont abundance and diversity within the Hindsville Formation occurs in the regressive stage of the lowermost higher-frequency cycle, which also represents the base of the regressive stage of the upper Mayes cycle.

DISCUSSION

Inclusion of the Ordnance Plant Member within the Upper Mayes Cycle

Huffman (1958) interpreted two transgressive-regressive depositional cycles within the Mayes Group, but placed the boundary between them at the contact between his “Moorefield Formation” (Pryor Creek Formation of this study) and the overlying Hindsville Formation. This placement was based on the interpretation of the contact as an unconformity, which Huffman (1958) supported with two lines of evidence. First was the apparent northward truncation of the Ordnance Plant Member below the Hindsville Formation in northern Mayes County, Oklahoma. This interpretation was based on apparent juxtaposition of the Hindsville Formation on increasingly older sections of the Ordnance Plant Member as the contact is traced northward. In central Mayes County, the Ordnance Plant Member typically consists of a lower shaly siltstone section, middle siltstone section, and upper shaly siltstone section. As Huffman (1958) noted, the middle siltstone transitions to a shaly siltstone and silty shale southward from central Mayes County, representing proximal to distal facies change. Huffman (1958) did not however interpret reciprocal facies changes in the lower and upper shaly sections northward from central Mayes County and attributed the absence of the upper shaly siltstone to removal by erosion. An alternative explanation is that the apparent superposition of the Hindsville Formation on the middle siltstone of the Ordnance Plant Member is the result of facies change of the upper shaly siltstone to siltstone in the more proximal position. Thinning of the Ordnance Plant Member northward from central Mayes County also seems to support the truncation interpretation of Huffman (1958), but coincident thinning of the entire Pryor Creek Formation implies possible depositional control. The second line of evidence cited by Huffman (1958) was the reported occurrence of clasts of Ordnance Plant Member in the basal Hindsville Formation outcropping southeast of location 3 of this study in Cherokee County, Oklahoma. This has not been confirmed, as we were unable to locate that referenced location, nor have similar occurrences been observed elsewhere within the study area. Where observed, the boundary between the Hindsville Formation and underlying Ordnance Plant Member appears conformable. It is possible, however, that local erosion of the uppermost Ordnance Plant Member occurred during the transition to higher-energy regressive deposition of the Hindsville Formation.

Both Huffman (1958) and Turmelle (1982) reported interfingering of lithofacies or lithologies typically assigned to different lithostratigraphic units within the Mayes Group. Although similar lithologic variation was observed during this investigation, such instances of "interfingering" appear predictable and ordered, and are therefore interpreted as higher-frequency shallowing-upward depositional cycles within both the lower Mayes cycle and upper Mayes cycle. Correlation of higher-frequency cycles, however, is less reliable in the lower Mayes cycle than the upper Mayes cycle (Figure 13). Observed differences between upper Mayes higher-frequency cycles between study sections are attributed to lateral facies variation.

Although Huffman (1958) interpreted two transgressive-regressive cycles in the Mayes Group, he included the Ordnance Plant Member in his lower cycle with the Bayou Manard and Lindsey Bridge members, leaving the Hindsville Formation as the sole unit in his second cycle. In addition to the contrasting stacking patterns of high-frequency cycles described above, inclusion of the Ordnance Plant Member in the upper Mayes cycle was done for two reasons. First, the Ordnance Plant Member unconformably overlies the Lindsey Bridge Member, whereas it conformably underlies the Hindsville Formation. Therefore, the Ordnance Plant Member shares a closer genetic relationship with the Hindsville Formation. Although Huffman (1958) interpreted an unconformity between the Ordnance Plant Member and Hindsville Formation, no definitive evidence was observed during this investigation supporting that interpretation. Instead, the unconformity between the Ordnance Plant Member and Lindsey Bridge Member is clearly defined in central Mayes County and is also present to the southeast in Adair County. These observations agree with the those of Swinchatt (1967) who noted an apparent truncation of the Lindsey Bridge Member along its contact with the overlying Ordnance Plant Member. Swinchatt (1967) described the contact as unconformable, which contradicts the conformable contact reported by Huffman (1958). Second, terrigenous quartz silt is common throughout the Mayes Group and tends to accumulate at or near the bases of cycles regardless of scale. Quartz silt is concentrated at the base of the Bayou Manard Member in central Mayes County. At location 12 in Mayes County and location 4 in Adair County, shallow-water (proximal shallow subtidal) ripple cross-laminated siltstone beds commonly occur at or near the base of high-frequency shallowing-upward cycles within the Hindsville Formation. At location 21 in Craig County, Oklahoma, the base of the Hindsville Formation includes a green-gray calcareous siltstone with ripple cross-laminations and vertical and horizontal burrows. Within the quarry walls, this siltstone bed thins and pinches out from north to south. Although lithostratigraphically included in the Hindsville Formation, this siltstone is similar to siltstones in the Ordnance Plant Member. It is possible that this green-gray siltstone represents the northern extent of the transgressive stage of the upper Mayes cycle and is equivalent to the Ordnance Plant Member farther south. Where the Hindsville Formation was observed in Ottawa County, it also includes a thin gray-green calcareous siltstone and silty calcareous shale near the base.

Sequence Stratigraphic Implications and Controls on Depositional Cyclicity

Sequence stratigraphic terminology was not applied to the Mayes Group earlier in this paper because the interpretations discussed herein were predominantly based on observations made at locations in central Mayes County and subsequently applied on a limited basis to other areas of northeastern Oklahoma. Thus, interpretations of Mayes Group depositional cyclicity are essentially one and two-dimensional. In this section, we address the sequence stratigraphy of the Mayes Group in northeastern Oklahoma is addressed using conodont biostratigraphy-based time-averaging of the interpreted depositional cycles and comparisons with studies of time-equivalent strata in North America.

Based on conodont biostratigraphic data, the span of time represented by the Mayes Group is 5 to 6 m.y., with both the lower and upper Mayes cycles representing up to 3 m.y. (Menning et al., 2006; Godwin et al., this volume). The lower and upper Mayes cycles are therefore interpreted as third-order sequences, with the entire Mayes Group representing a second-order sequence relative to the order assigned to the lower and upper Mayes cycles. Higher-frequency shallowing-upward cycles represent approximate time spans of between 300 and 550 k.y. and are therefore interpreted as fourth-order sequences.

Of specific interest is the comparison between observations of the Mayes Group in northeastern Oklahoma and the sequence stratigraphic model of Handford (1995) and Handford et al. (2014) for temporally equivalent strata in northern Arkansas. Handford (1995) proposed the "Marshall Sequence" for Meramecian through Chesterian strata in northern Arkansas. The "Marhsall Sequence" sediment was deposited along followingthe development of a sequence-bounding unconformity (equivalent to the sub-Mayes unconformity of this study) and down-dip correlative conformity. Within the "Marshall Sequence", Handford (1995) interpreted the Moorefield Formation as the lowstand systems tract, the Hindsville Formation and Batesville Sandstone as the initial part of the transgressive systems tract, the Fayetteville Shale as the main part of the transgressive systems tract, and the Pitkin Limestone as the highstand systems tract. Although this interpretation does not address third-order and higher-frequency depositional sequences similar to those interpreted in the Mayes Group, the overall geometry of the Mayes Group in northeastern Oklahoma compares favorably with that of the Moorefield Formation and Hindsville Formation of the "Marshall Sequence" in northern Arkansas. Low-energy deep subtidal facies of the Pryor Creek Formation in Oklahoma and Moorefield Formation in northern Arkansas unconformably overlie the Boone Group and interpreted high-frequency shallowing-upward cycles appear to onlap the unconformity surface. In both instances, the lowstand systems tract thins and pinches out updip and high-energy carbonate shoal facies of the Hindsville Formation rest unconformably on pre-Mayes Group strata. At two locations in Boone County, Arkansas, where the Hindsville Formation rests unconformably on the Boone Group, the base of the formation includes brown-gray calcareous shale, greenish-gray calcareous siltstone, and thin lenses of calcareous sandstone. Here again, the initial transgressive phase of the Hindsville Formation is dominantly composed of terrigenous silt and clay and is possibly correlative to the Ordnance Plant Member of northeastern Oklahoma. It is likely that the "Marshall Sequence" represents a supersequence of which the third-order sequences (lower and upper Mayes cycles) are a part.

Like the Mayes Group of northeastern Oklahoma and the "Marshall Sequence" of Handford (1995), Lane (1974) identified a Meramecian-Chesterian basinward-thickening depositional wedge in southeastern New Mexico and west Texas consisting of the Rancheria and Helms formations, which was interpreted by Bachtel and Dorobek (1998) as a single depositional sequence. Interpreted third and fourth-order depositional sequences in the Mayes Group appear to correspond to, or are similar to those reported in the Appalachian region in the eastern United States (Miller and Eriksson, 2000; Smith and Read, 2000; Al-Tawil and Read, 2003; Al-Tawil et al., 2003; Wynn and Read, 2007). Al-Tawil et al. (2003) interpreted the Appalachian Greebrier Group, which is temporally-correlative to the Mayes Group, as the transgressive stage of a larger supersequence that includes overlying strata equivalent to the Fayetteville Shale and younger strata.

Late Paleozoic glaciation and early phases of Ouachita tectonism are herein considered in terms of their relative influence on the observed stratigraphic architecture and cyclicity of the Mayes Group. Glacio-eustatic control on Mississippian deposition prior to and during the formation of the Mayes Group is documented in a number of studies (e.g. Isaacson et al., 2008; Kammer and Matchen, 2008; Bishop et al., 2009; Giles, 2009), and is herein interpreted as the primary control on the higher-frequency cycles (fourth-order sequences) observed in both the lower and upper Mayes cycles. Third-order depositional sequences, represented by the lower and upper Mayes cycles, correspond to the sea-level curve published by Ross and Ross (1985) for the Upper Mississippi River Valleywhere a major unconformity occurs below the Meramecian upper St. Louis Limestone (Bayou Manard Member; see Godwin et al., this volume) and a second unconformity below the Chesterian Ste. Genevieve Limestone. The Lindsey Bridge Member and Ordnance Plant Member are considered Chesterian and probably equivalent to the Ste. Genevieve Limestone (Godwin et al., this volume). Consequently, the decline in relative sea-level between the St. Louis and Ste. Genevieve limestones (Ross and Ross, 1985) may correspond to the unconformity between the lower and upper Mayes cycles. Syndepositional tectonics during the Kinderhookian and Osagean is evidenced by post-Osagean uplift and erosion (i.e. sub-Mayes unconformity) (Huffman, 1958). Syndepositional forebulge uplift and relaxation were invoked as mechanisms controlling the stratigraphic architecture of Kinderhookian through basal Meramecian strata in Oklahoma, Kansas, Arkansas, and Missouri by Mazzullo et al. (2016). Houseknecht et al. (2014) suggested that thinning of the Moorefield Formation in northern Arkansas resulted from syndepositional faulting. In both cases, structural movement was attributed to incipient Ouachita tectonism. Syndepositional tectonism continued into the Meramecian as evidenced by stratigraphic relationships within uppermost Boone Group strata in the Tri-State Mining District of northeastern Oklahoma (Godwin et al., this volume), but it is not clear, however, if structural movement continued during deposition of the Mayes Group. It is likely that many of the larger paleotopographic relief features along the sub-Mayes unconformity and resultant thickness and facies variations observed in the lower Mayes cycle resulted from a a combination of the uplift and erosion, as interpreted by previous workers, and glacio-eustasy. More consistent thickness of units in the upper Mayes cycle suggests that the depositional surface was relatively stable and that post-Mayes Group flooding, represented by deposition of the Fayetteville Shale, was glacio-eustatic in nature.

SUMMARY

This investigation evaluated and re-interpreted the Mayes Group in light of modern stratigraphic concepts. As a result, five (5) depositional facies associations and a hierarchy of cyclicity were defined. Recognizing facies stacking patterns and distribution, as well as identifying important stratigraphic surfaces in the Mayes Group provided evidence to support revising current lithostratigraphic boundaries and laid the foundation for more confident correlation of outcrop stratigraphy to the subsurface of Oklahoma.

The Mayes Group records a primary shallowing-upward or transgressive-regressive depositional cycle following subaerial exposure and erosion associated with the sub-Mayes unconformity. This primary depositional cycle appears equivalent to a second order depositional sequence or the lowstand and transgressive systems tracts of a larger depositional sequence that includes the overlying Fayetteville Shale and Pitkin Limestone (e.g. Handford, 1995). The Mayes Group primary cycle consists of two secondary transgressive-regressive cycles, herein termed the lower Mayes cycle and upper Mayes cycle, each of which represents a third-order depositional sequence. Separating the lower and upper Mayes cycles is the previously unrecognized unconformity between the Lindsey Bridge and Ordnance Plant members of the Pryor Creek Formation. The lower Mayes cycle and upper Mayes cycle are both considered a third-order sequence of up to 3 m.y. in duration, each. Both cycles contain higher-frequency depositional cycles bounded by flooding surfaces. These higher-frequency cycles are believed to represent equivalent to fourth-order sequences, with temporal spans of 300 to 550 k.y.

The interpretations provided use depositional facies, stratigraphic surfaces and lateral facies changes to clarify ambiguous lithostratigraphic relationships in the Mayes Group. We believe that this work provides a foundation for subsequent high-resolution stratigraphic studies seeking to construct a comprehensive regional sequence stratigraphic model for Meramecian and Chesterian ramp carbonates.

ACKNOWLEDGEMENTS

First and foremost, we would like to remember Darwin R. Boardman, II, who passed away in January of 2015. We continue miss his enthusiasm for geology and life.

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FIGURES

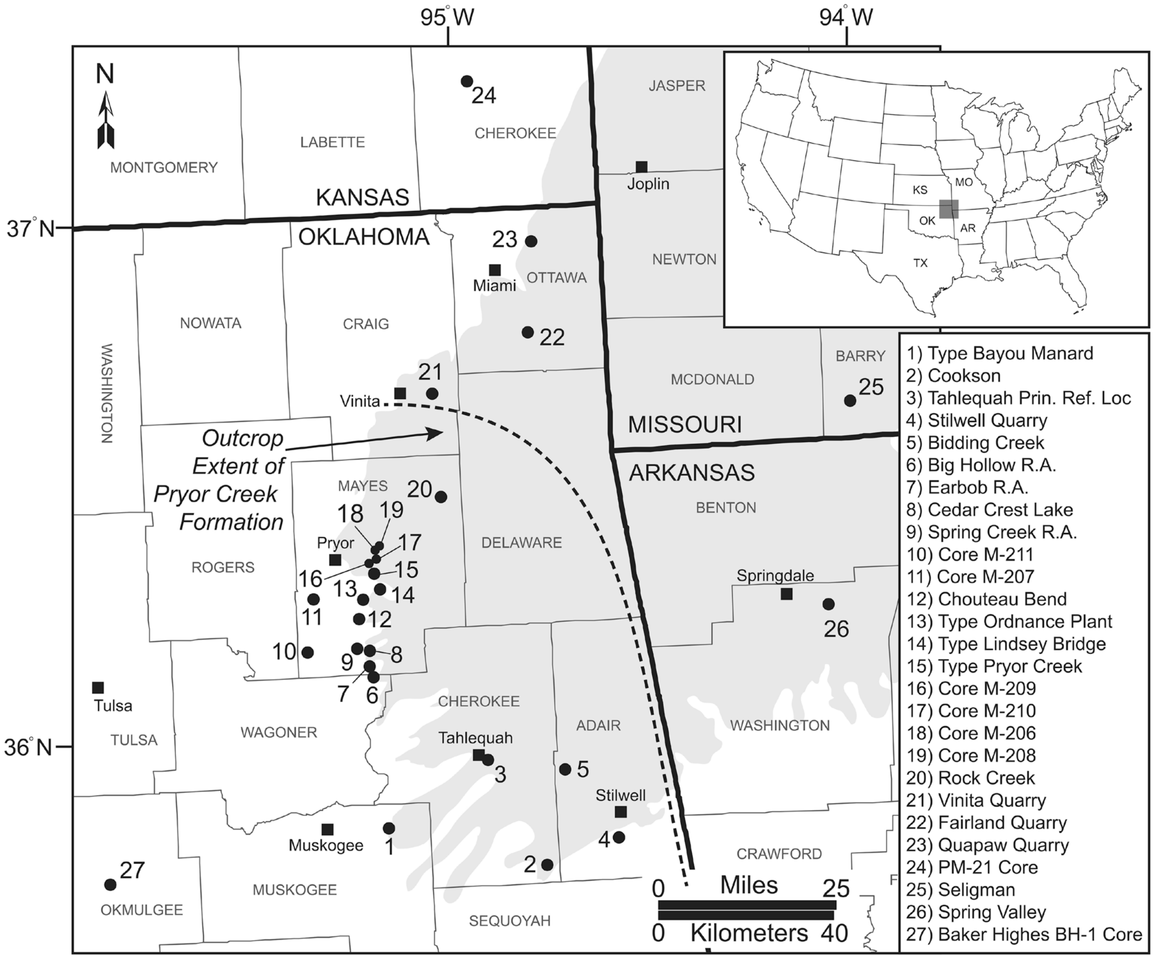

Figure 1. Study area map with locations of reference sections discussed in the text. Light gray shaded area is Mississippian outcrop area. Also shown is the known extent of the Pryor Creek Formation.

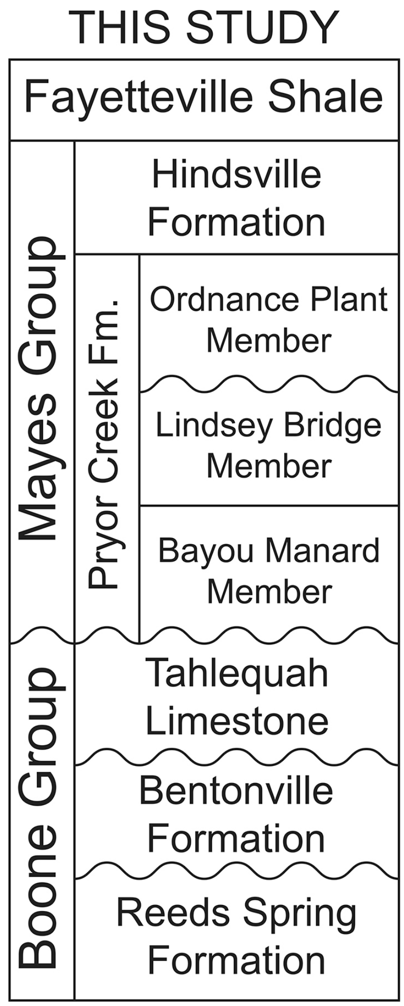

Figure 2. Lithostratigraphic nomenclature of the Mayes Group within northeastern Oklahoma, including interpreted unconformities. Modified from Mazzullo et al. (2013) and Godwin et al. (this volume).

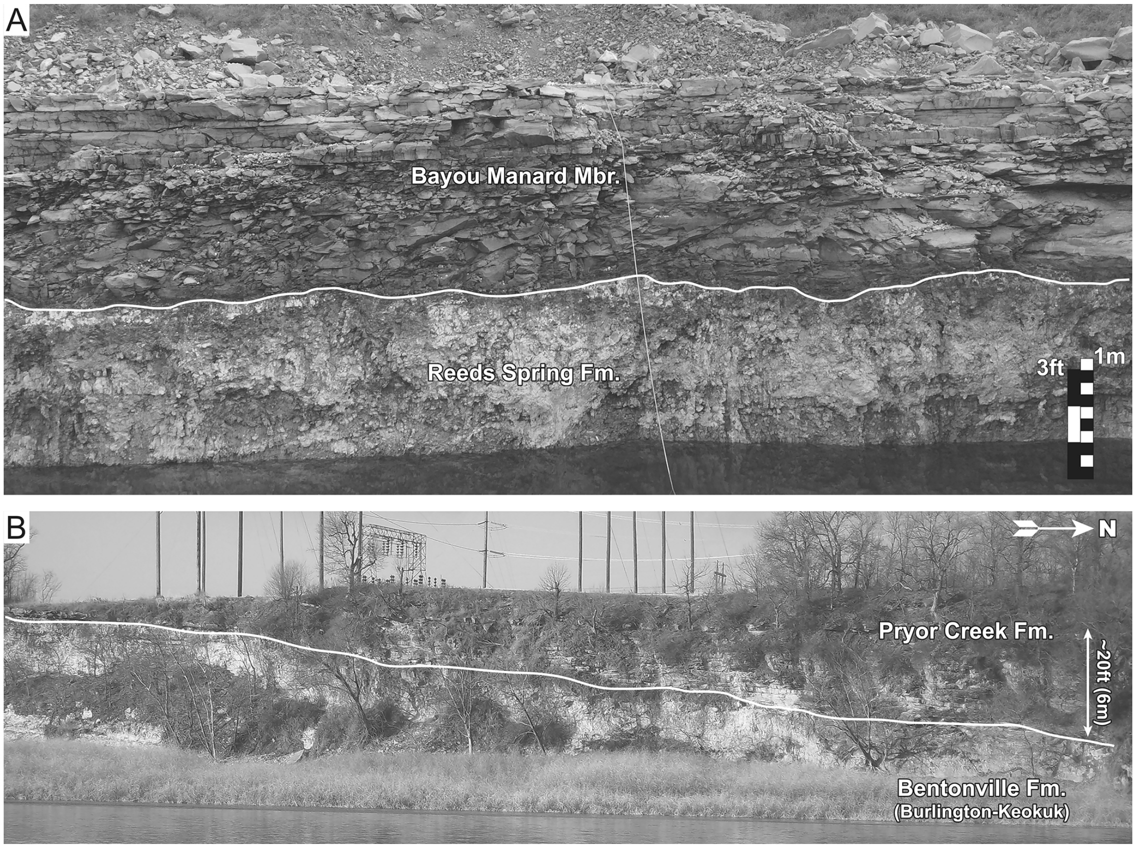

Figure 3. Sub-Mayes Unconformity. (A) Location 15, south high-wall section, with small-scale paleotopography expressed as an irregular surface. (B) Location 13, illustrating dip of Pryor Creek Formation across paleotopographic high along the top of the Boone Group, here represented by the Bentonville Formation.

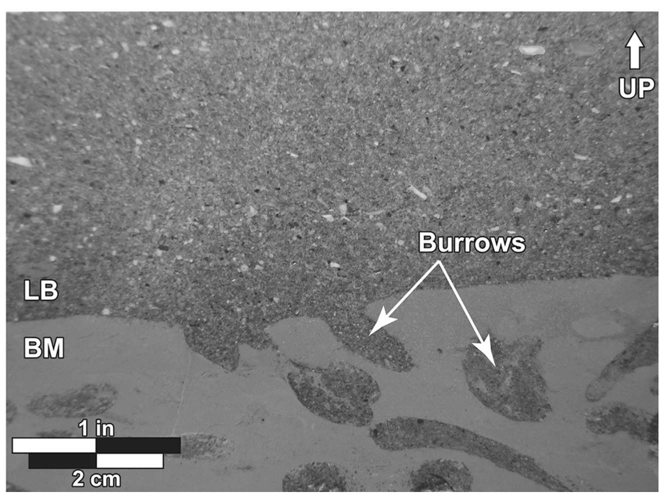

Figure 4. Contact between Bayou Manard and Lindsey Bridge Members.

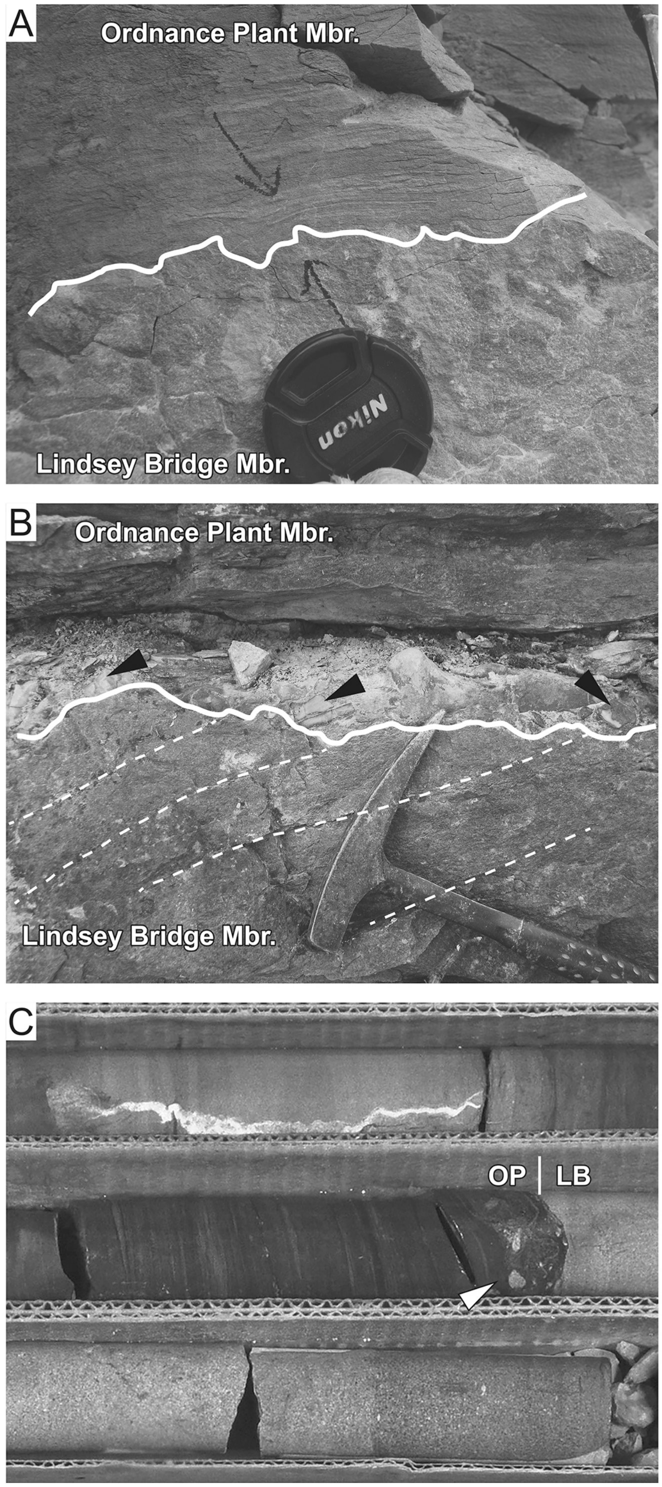

Figure 5. (A-C) Unconformable contact between the Lindsey Bridge Member (LB) and Ordnance Plant Member (OP) at (A) location 15, (B) location 4, and (C) location 18. White arrows = clasts of Lindsey Bridge Member; black arrows = chert clasts. Diameter of core is 1 inch (2.5 cm).

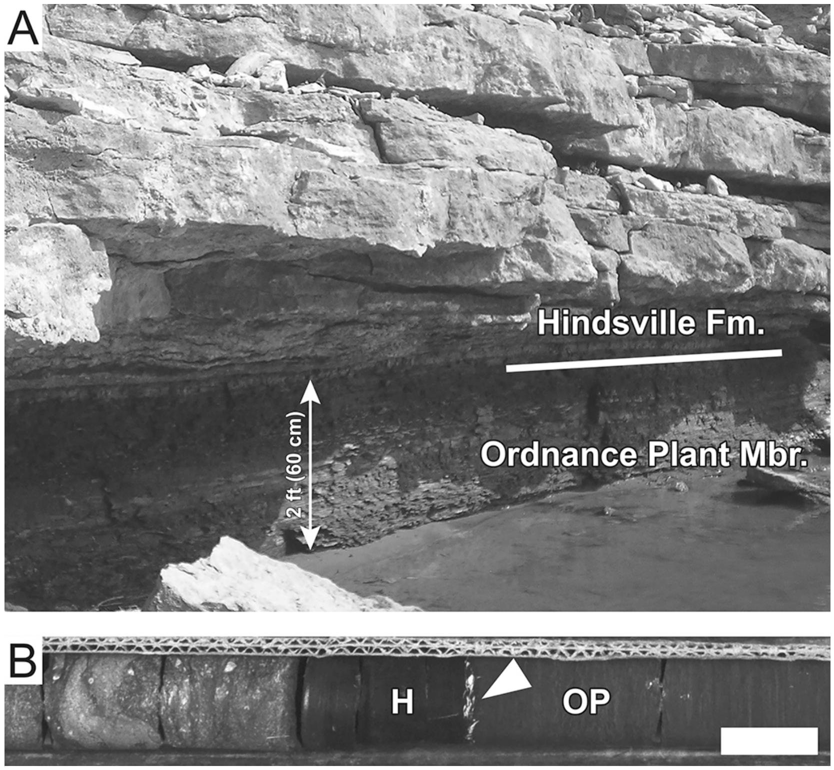

Figure 6. Contact between the Ordnance Plant Member and Hindsville Formation at (A) location 12 and (B) location 17. White arrow in (B) points to inferred contact with skeletal lag.

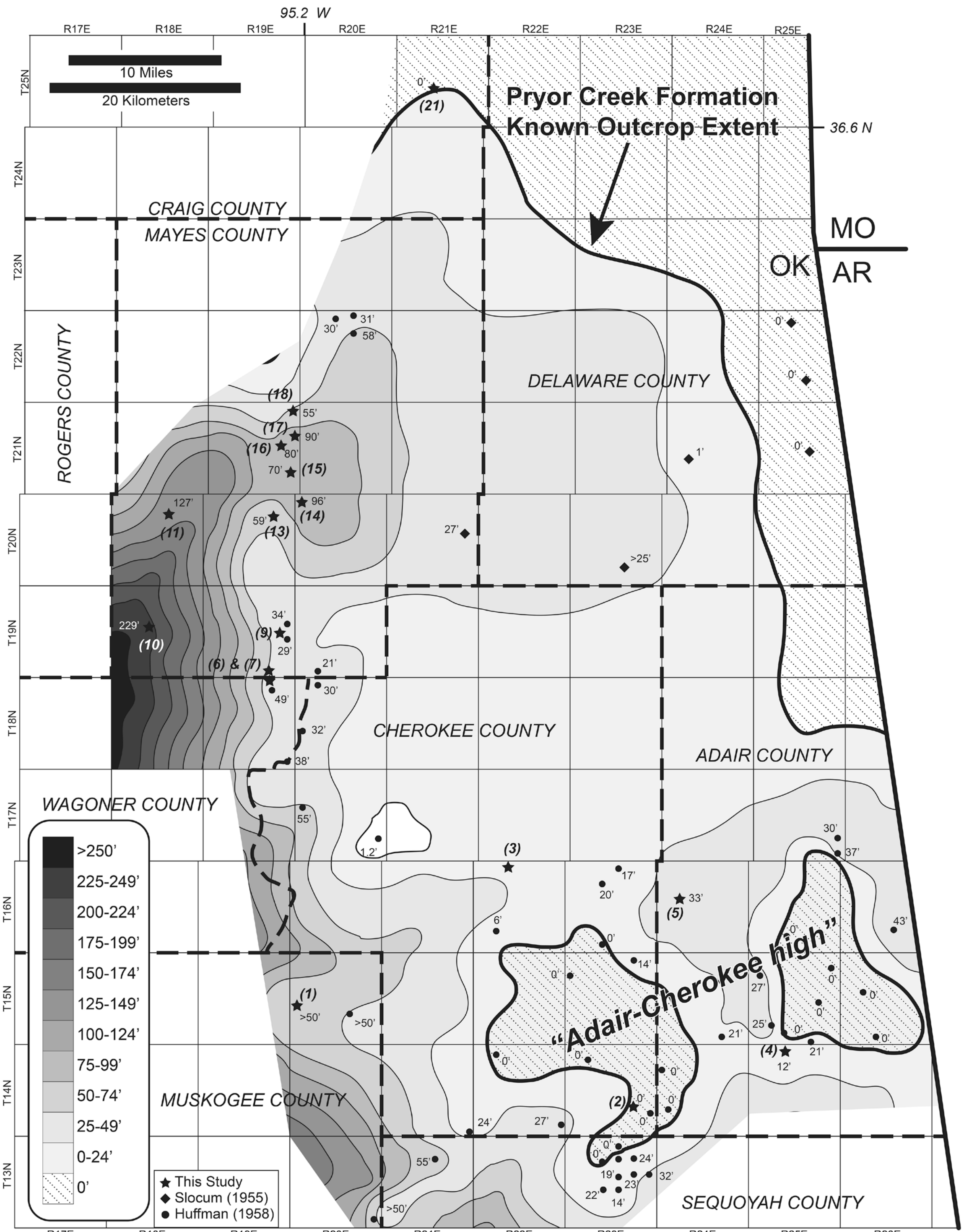

Figure 7. Gross thickness map of the Pryor Creek Formation. Contour interval is 25 feet (7.6 meters). Primary study area is the Mayes Group type area. Locations measured and described in this study are shown with numerical identifiers in parentheses. Other locations are from Slocum (1955; in Delaware County) and Huffman (1958).

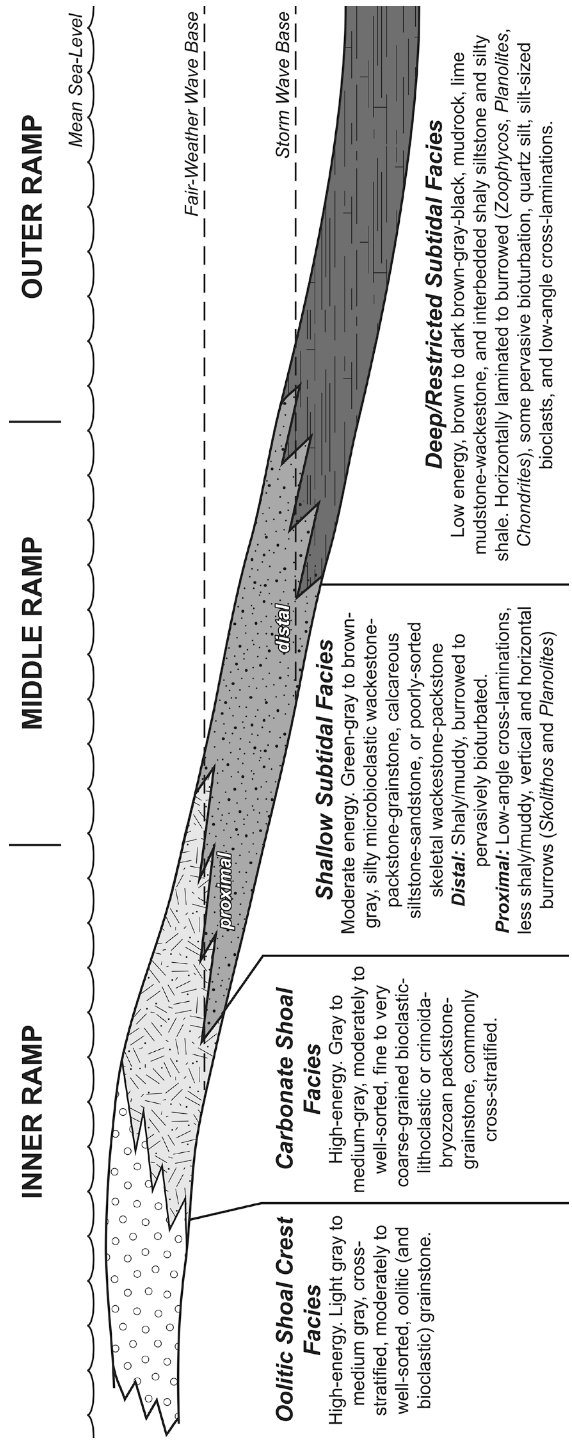

Figure 8. Generalized dip-oriented model for the Mayes Group, assuming a ramp-style platform geometry, illustrating the distribution and relationships of depositional facies associations.

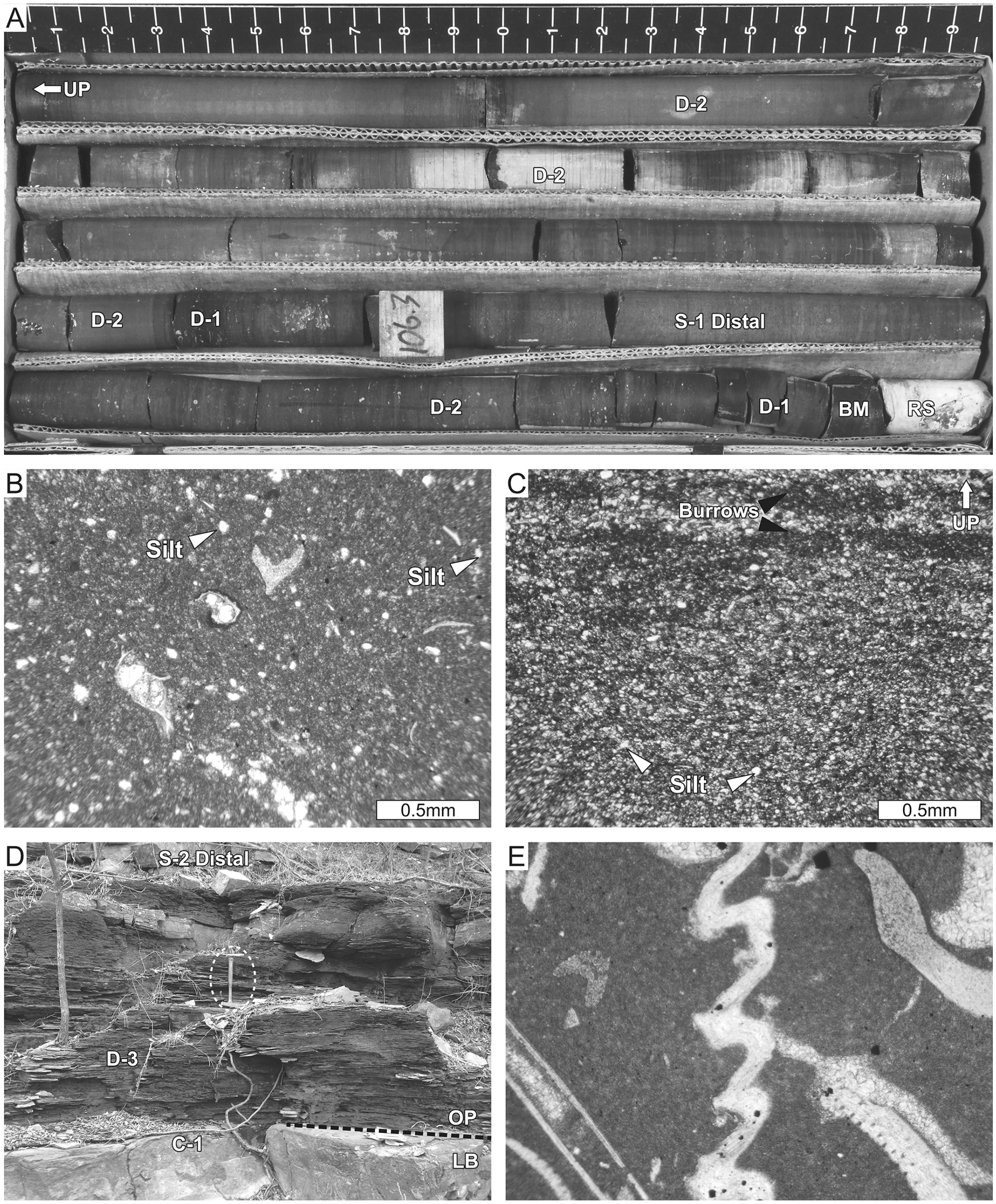

Figure 9. Deep subtidal facies association. (A) Bayou Manard Member (BM), core M-210 (location 17) illustrating deep subtidal facies (D-1 and D-2) and distal shallow subtidal facies (S-1 Distal). Core depths from 109.4 to 100.0 feet (33.3 to 30.5 m),core is 1 inch (2.5 cm) in diameter. (RS – Reeds Spring Formation). (B) Thin-section microphotograph of lithofacies D-1 in Bayou Manard Member at location 13. (C) Thin-section microphotograph of lithofacies D-1 in Lindsey Bridge Member at location 15. (D) Outcrop photograph of distal shallow subtidal facies (S-3 distal) and deep subtidal facies (D-3) in the Ordnance Plant Member (OP) at location 7, overlying carbonate shoal facies (C-1) of the Lindsey Bridge Member (LB). Hammer in is 12 inches (30.5 cm) long. (E) Thin-section microphotograph of deep subtidal facies (lithofacies D-2) in Hindsville Formation at location 12.

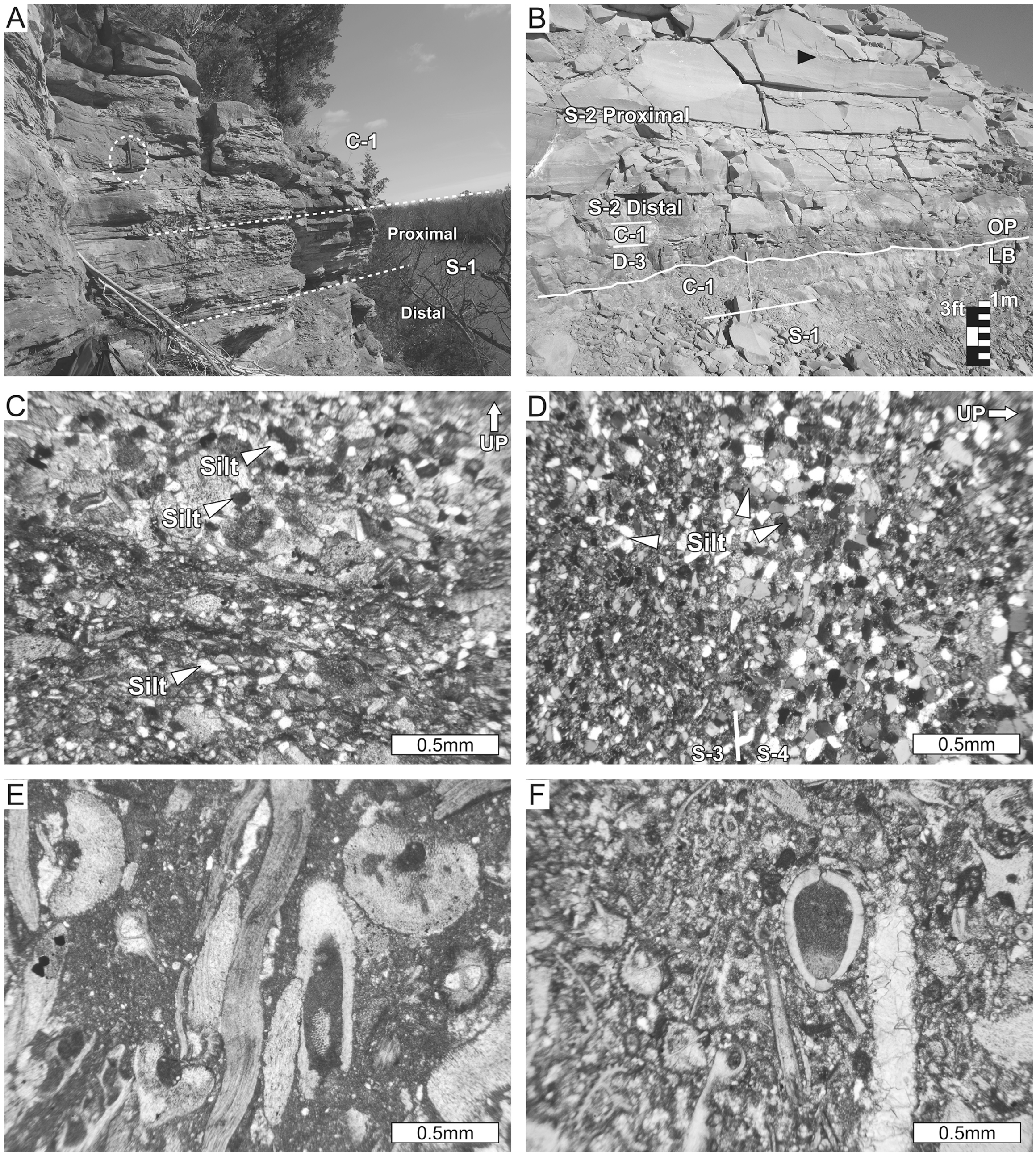

Figure 10. Shallow subtidal facies association. (A) Outcrop photograph from location 14 showing the succession of lithofacies in the Lindsey Bridge Member from shallow subtidal facies (S-1), through carbonate shoal facies (C-1). (B) Shallow subtidal facies (S-2), carbonate shoal facies (C-1) and thin deep subtidal facies (D-3) in the Ordnance Plant Member (OP) overlying carbonate shoal (C-1) and shallow subtidal facies (S-1) in the Lindsey Bridge Member (LB) in the north high-wall section at location 15. (C) Shallow subtidal facies from the Lindsey Bridge Member at location 14. (D) Shallow subtidal facies in the Ordnance Plant Member (OP) at location 15 (south high-wall section). (E and F) Shallow subtidal facies the Hindsville Formation from location 12.

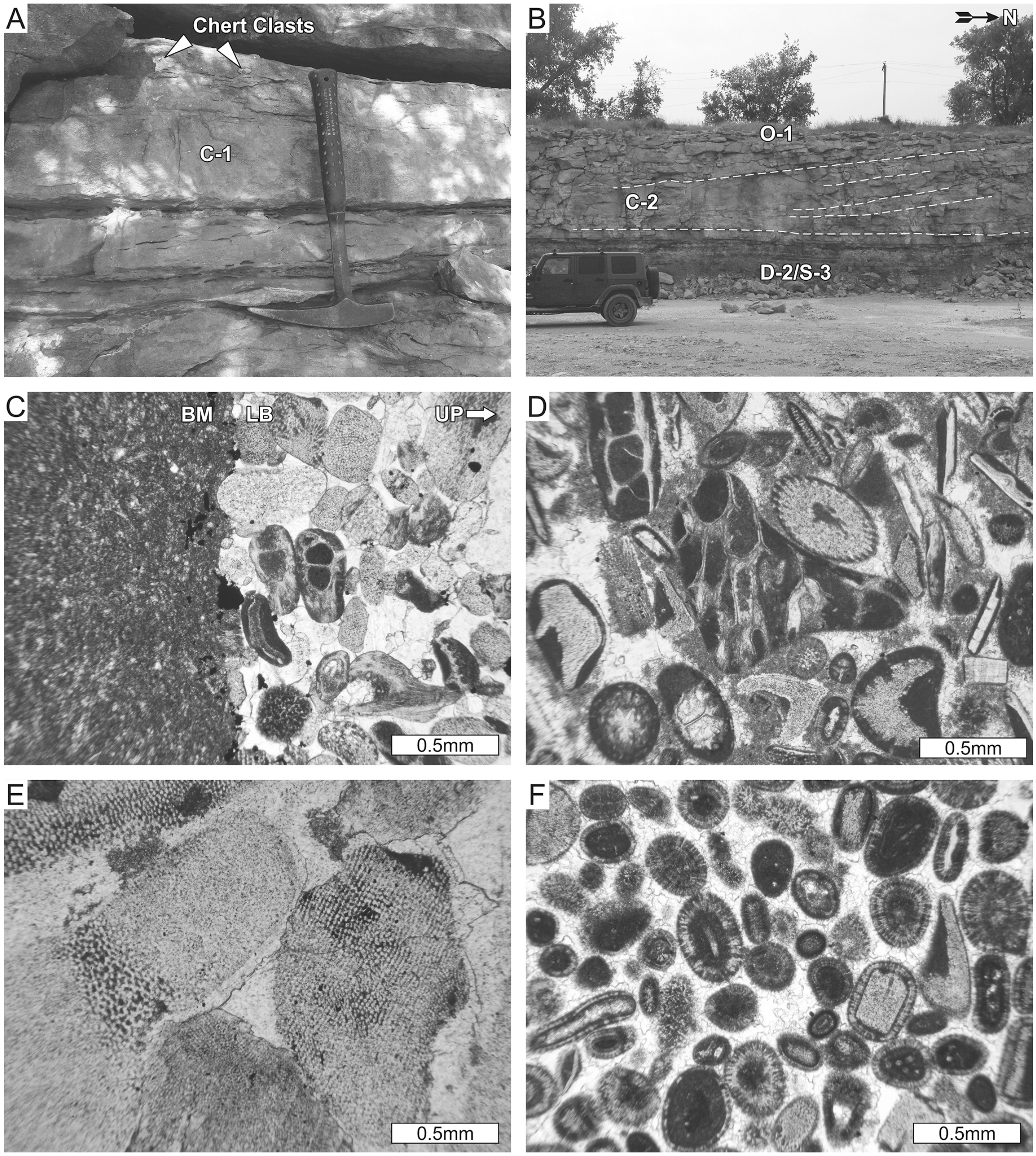

Figure 11. Carbonate shoal and oolitic shoal crest facies associations. (A) Outcrop photograph of carbonate shoal facies (C-1) with sand to gravel-sized chert clasts in the Lindsey Bridge Member at location 14. (B) Outcrop photograph showing southward prograding carbonate shoal facies and oolitic shoal crest facies of the Hindsville Formation at location 15, overlying deep to shallow subtidal facies (D-2/S3). Vehicle is 6 feet (1.8 m) tall. (C) Thin-section microphotograph of carbonate shoal facies (lithofacies C-1) of the Lindsey Bridge Member (LB) overlying deep subtidal facies (lithofacies D-1) of the Bayou Manard Member (BM) at location 13. (D and E) Thin-section microphotographs of two expressions of carbonate shoal facies (lithofacies C-2) of the Hindsville Formation at location 12. (F) Thin-section microphotograph of shoal crest facies of the Hindsville Formation from location 15.

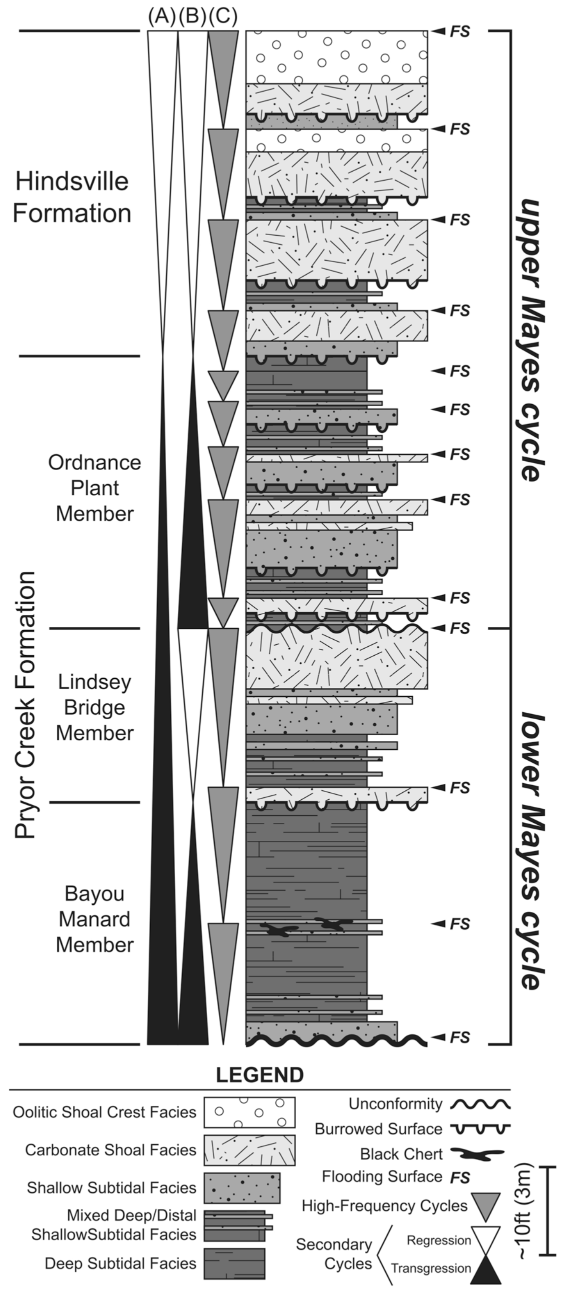

Figure 12. Idealized Mayes Group vertical facies succession and interpreted depositional cyclicity including the (A) primary transgressive-regressive cycle, (B) two secondary transgressive-regressive depositional cycles (upper and lower Mayes cycles), and (C) higher-frequency cycles within the Mayes Group type area of central Mayes County, Oklahoma based upon a compilation of surface exposures and subsurface cores shown in Figure 1.

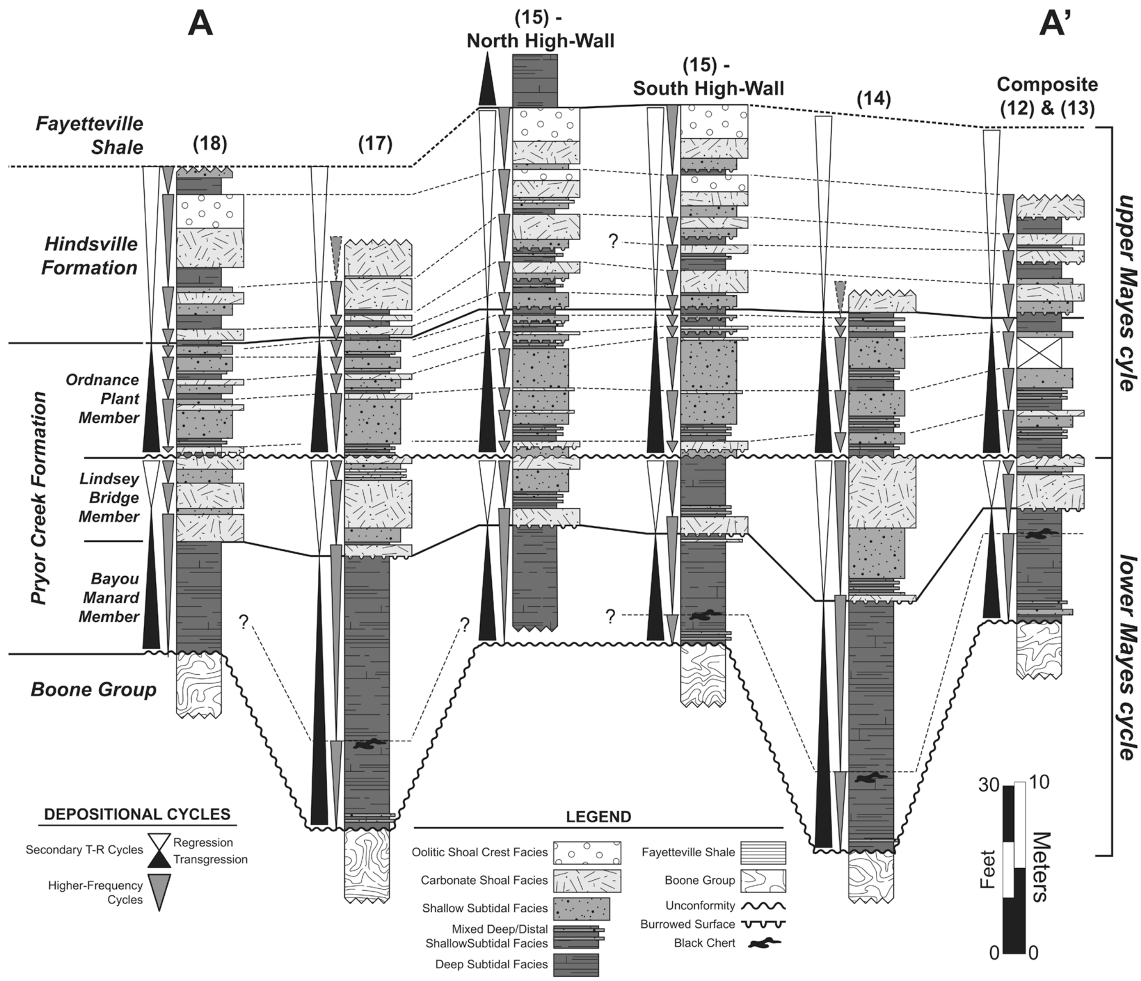

Figure 13. North-to-south cross-section A-A'. Cross-section line is shown in map inset in Figure 14. No horizontal scale.

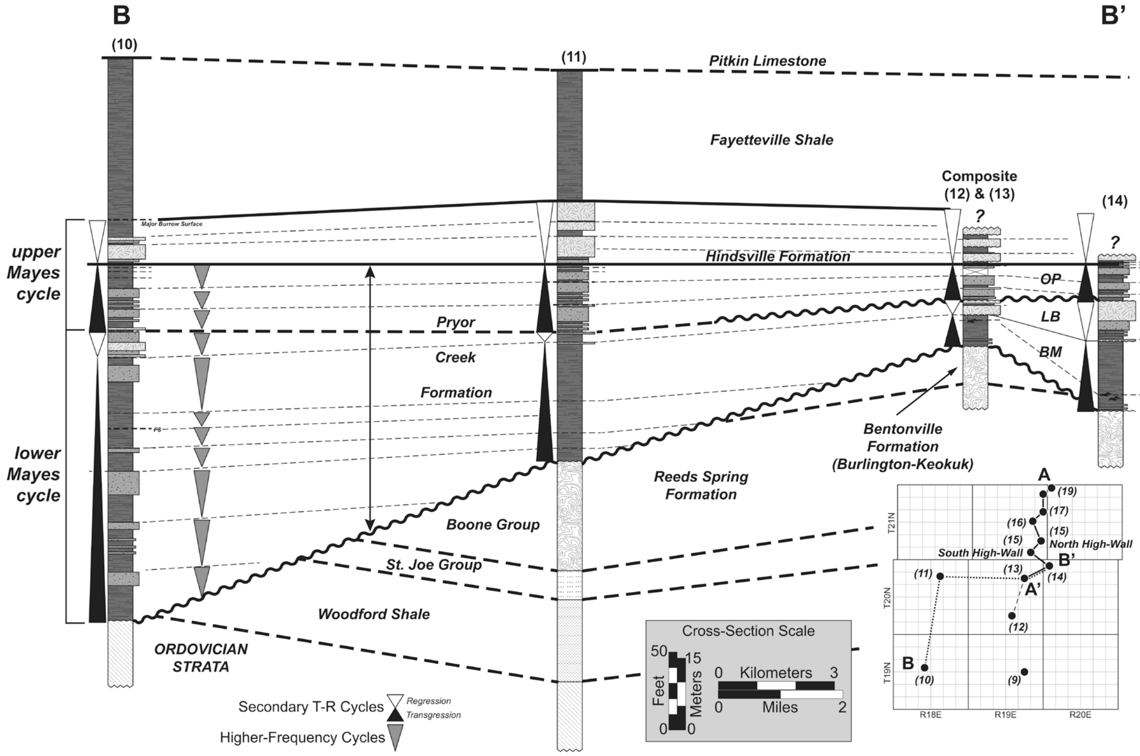

Figure 14. West-to-east cross-section (B-B' in map inset) from the Mayes Group type area (locations 13 and 14) into the shallow subsurface of southwestern Mayes County (locations 10 and 11) illustrating the truncation of pre-Mayes strata by the sub-Mayes unconformity and subsequent expansion of the lower Mayes cycle. Multiple higher-frequency shallowing-upward cycles (dashed lines and gray triangles) are interpreted within both the lower and upper Mayes cycles.

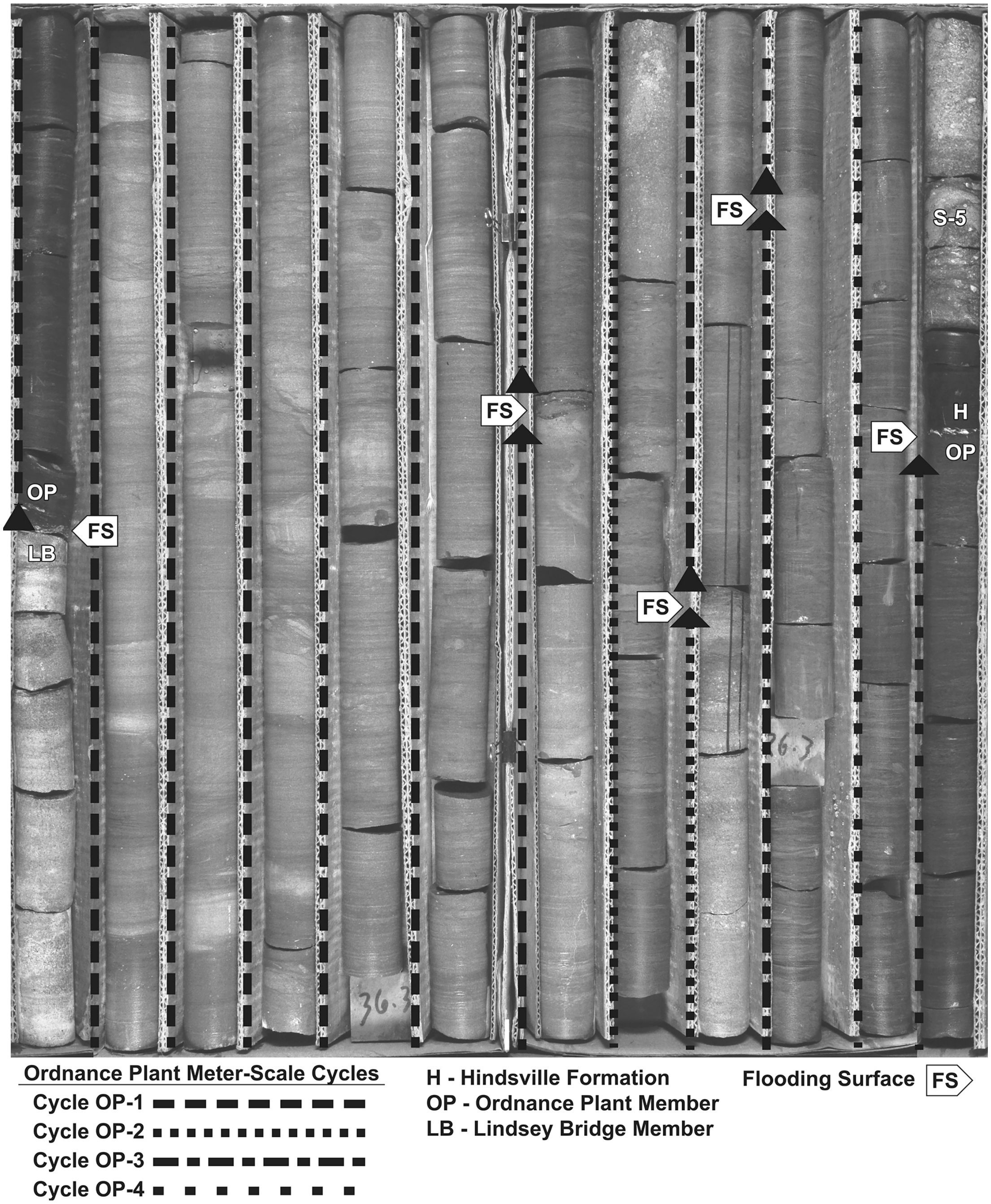

Figure 15. Higher-frequency cycles in the Ordnance Plant Member of the Pryor Creek Formation in subsurface core at location 17. Core interval shown is from 44 to 21 feet (13.4 to 6.4 m). Three to four high-frequency cycles (variously dashed lines) are interpreted between the base of the Ordnance Plant Member (OP) and base of the Hindsville Formation (H). Ordnance Plant Member unconformably overlies carbonate shoal facies (C-1) of the Lindsey Bridge Member (LB). Ordnance Plant Member cycles generally consist of deep subtidal facies and shallow subtidal facies, with some carbonate shoal facies, and together display an overall deepening-upward succession culminating with the basal deep subtidal facies of the Hindsville Formation.

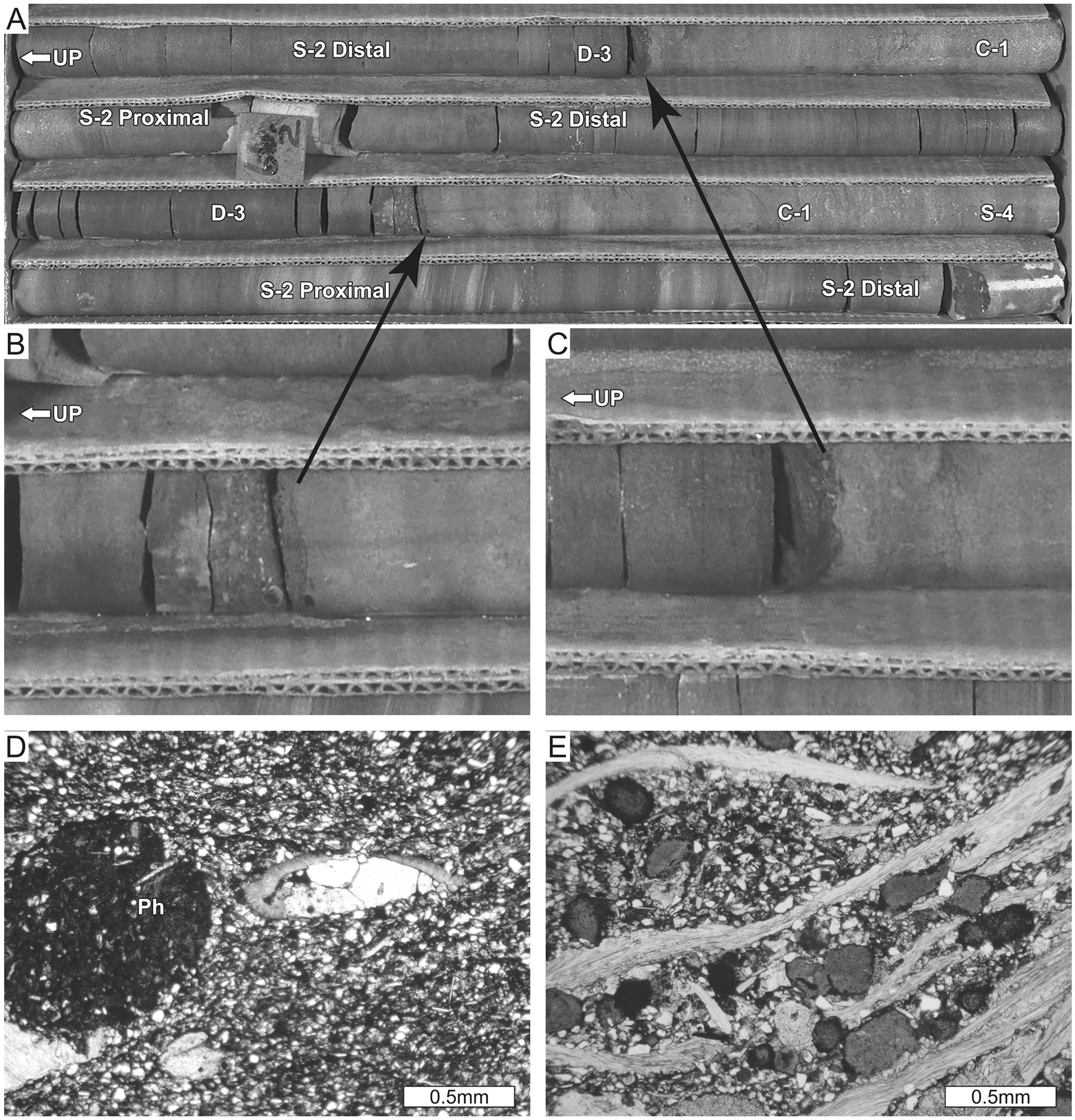

Figure 16. Flooding Surfaces. (A-C) Ordnance Plant Member from location 18 illustrating positions of multiple flooding surfaces separating relatively high-energy carbonate shoal facies (C-1) and proximal shallow subtidal facies (S-2 Proximal) from relatively low-energy deep subtidal facies (D-3) and distal shallow subtidal facies (S-2 Distal). Core depth shown in (A) is from 71.7 to 63.8 feet (21.9 to 19.4 m). Core diameter is 1 inch (2.5 cm).

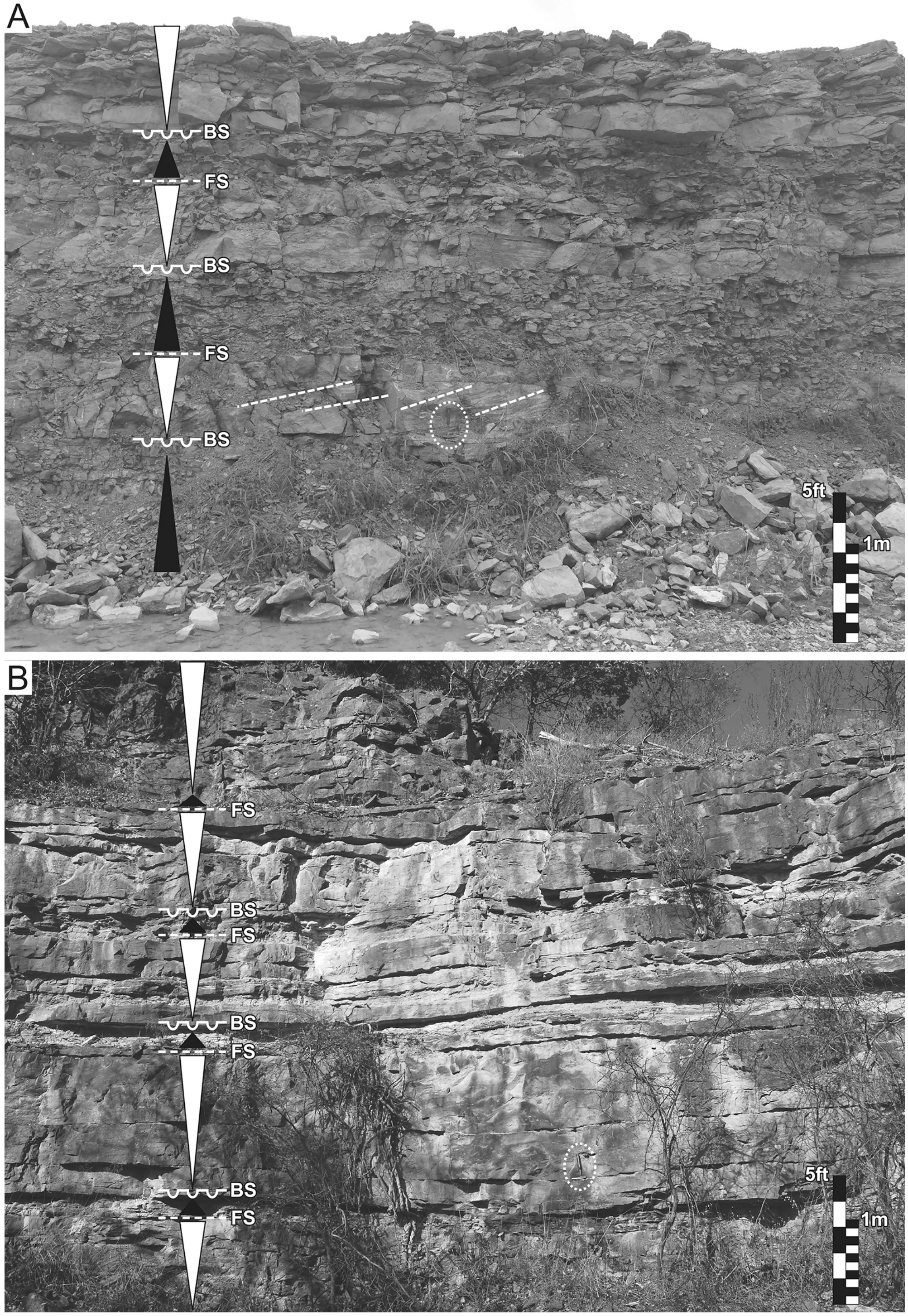

Figure 17. Higher-frequency cycles in the Hindsville Formations bounding by flooding surfaces (FS). These cycles also include interpreted transgressive stages (black triangles) and regressive stages (white triangles) separated by observed burrowed surfaces (BS). Also shown are deep subtidal facies (D-2), shallow subtidal facies (S-3), carbonate shoal facies (C-2), and oolitic shoal crest facies (O-1). (A) Location 15 (south short-wall section). (B) Sitlwell Quarry (location 4) in Adair County, Oklahoma. 12 inch (30.5 cm) rockhammer (circle) for scale. Dashed lines in (A) illustrate cross-stratification.

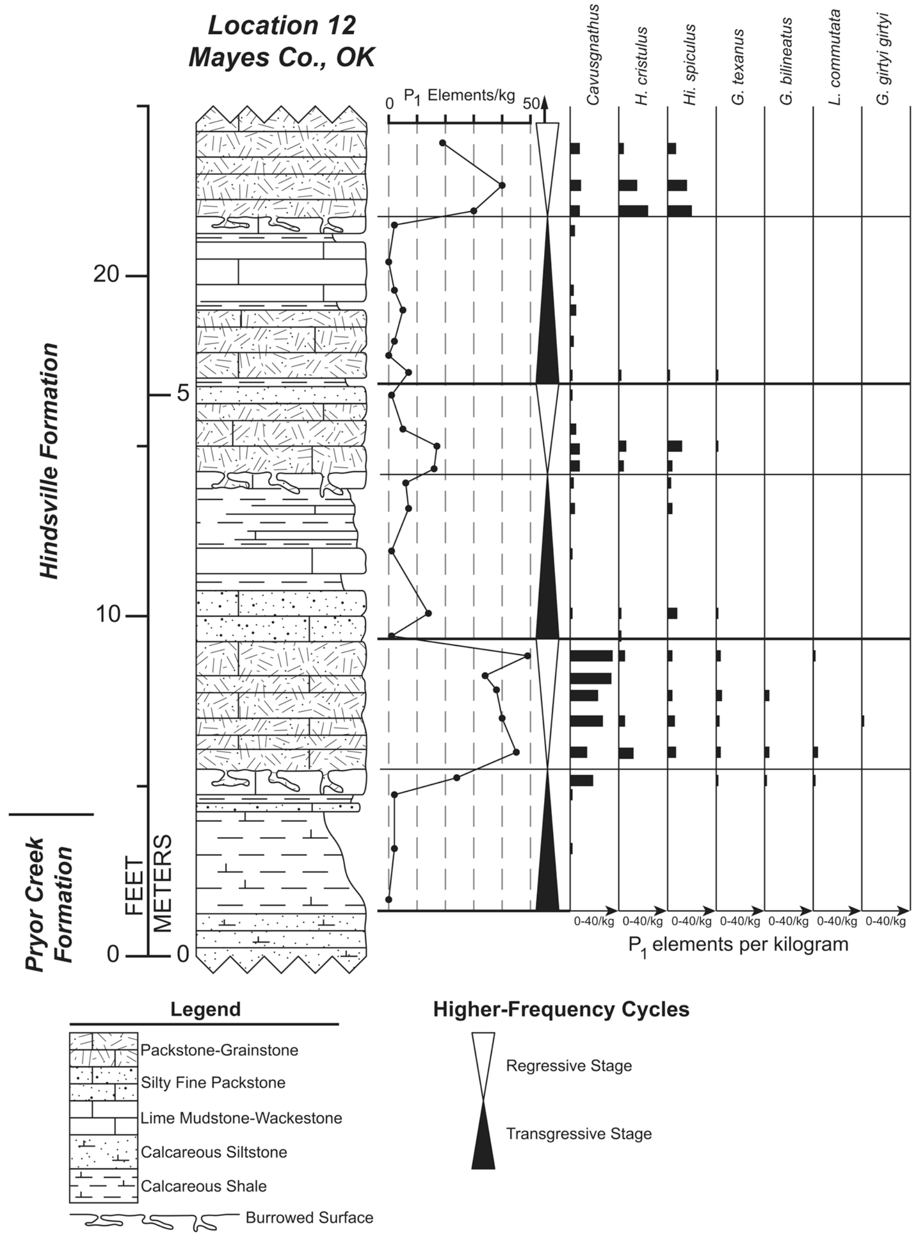

Figure 18. Correlation between interpreted higher-frequency depositional cycles and conodont recoveries in the Hindsville Formation at location 12.

CHAPTER V

SUMMARY AND CONCLUSIONS

The papers included within this dissertation represent elements of ongoing research concerning Mississippian strata of the southern mid-continent, specifically Meramecian and Chesterian (Visean) rocks exposed across the southwestern flank of the Ozark Uplift in Oklahoma, Missouri, and Arkansas. As with all scientific research, the results interpretations and conclusions presented within those three papers are in no way final, nor are they sure to be agreeable to everyone. They do, however, serve to advance our understanding of these rocks and provide a modern stratigraphic foundation for continued study.

Although the subject of lithostratigraphy may seem elementary to some, at least in light of the more quantitative methods in the geosciences, it remains the foundation of outcrop-based (as well as subsurface) sedimentary geology and lithostratigraphic nomenclature serves as a common language with which working geologists may communicate. Lithostratigraphy and the ability of geologists to communicate through reasonable lithostratigraphic nomenclature is essential both the construction of geologic models. The proposed lithostratigraphic revisions presented in chapters II and III are aimed at making more sense out of strata of the upper Boone Group and Mayes Group, most of which have been little studied during the past six decades. Proposal of Pryor Creek Formation for lower Mayes Group strata in northeastern Oklahoma, in lieu of the term "Moorefield Formation" as defined by Huffman (1958), is done because the application of the term "Moorefield" requires constant clarification as to whether one is discussing the type Moorefield Formation of northern Arkansas or to the strata of northeastern

Oklahoma. The reason this is important is that the type Moorefield Formation of northern Arkansas is shale-dominated, whereas equivalent strata in northeastern Oklahoma (i.e. Pryor Creek Formation) are limestone and calcareous siltstone-dominated. Thus, a basic lithostratigraphic differentiation is justifiable based on the lithologic difference. Although Pryor Creek Formation strata do become shalier as they are traced southward, they share a greater affinity with the Caney Shale of southern Oklahoma to which they are geographically closer and appear to be physically continuous. Of note, the Pryor Creek Formation is not currently known to be continuous with the type Moorefield Formation.

Prior to this study, the lowest stratigraphic unit of the Mayes Group was considered to be the Tahlequah Member of the "Moorefield Formation" based on the definitions of Huffman (1958). In both chapter II and chapter III, a proposal is made to remove the "Tahlequah" from the Mayes Group and include it within the Boone Group as the "Tahlequah Limestone". This lithostratigraphic change is predicated on evaluation of conodont biostratigraphic data. Conodont fauna collected from the Tahlequah Limestone are almost identical to those of the Ritchey Formation of the Boone Group in the Tri-State Mining District of Oklahoma, Missouri, and Kansas. Furthermore, the Tahlequah Limestone is separated from the Bayou Manard Member of the Pryor Creek Formation by a major regional unconformity, herein designated the "sub-Mayes unconformity". At this point it becomes important to understand the nature of the strata overlying the Ritchey Formation in the Oklahoma portion of the Tri-State Mining District, both in terms of their relationship to the Boone Group and Mayes Group. It also becomes important to recognize the common application of interpreted equivalency of strata of the southern mid-continent to those of the Upper Mississippi River Valley, which is both the Mississippi type area and the area in which conodont studies of Mississippian strata in North America began. For example, the Ritchey Formation and Tahlequah Limestone are considered to be equivalent to all or part of the Warsaw Formation of the Upper Mississippi Valley. In the redefinition of the Boone Group proposed by Mazzullo et al. (2013), post-Ritchey Formation strata of the Moccasin Bend

Formation and Quapaw Limestone were not included. This was first and foremost a result of the incompleteness of work concerning these strata at the time of publication. It is clear from further evaluation, however, that the Moccasin Bend Formation and Quapaw Limestone represent a continuation of deposition that characterized older Boone Group strata, including the Reeds Spring Formation, Bentonville Formation, and Ritchey Formation. The Moccasin Bend Formation and Quapaw Limestone are therefore included in the Boone Group in this study, as shown in Chapter III. This also follows the results of McKnight and Fischer (1970) who included the Moccasin Bend "member" within their Boone "formation". Excluded from the Boone "formation" of McKnight and Fischer was the Quapaw Limestone. This was done presumably because it lacked the diagenetic chert that so characterizes much of the Boone Group. Conodont recoveries demonstrate the Moccasin Bend Formation and Quapaw Limestone to be of early-late Meramecian age and equivalent to the St. Louis Limestone of the Upper Mississippi River Valley. Because strata of the southern mid-continent are so often discussed in terms of their equivalency to strata of the Upper Mississippi River Valley (i.e. Mississippian type area), we must be careful in such application. For example, the Bayou Manard Member of the Pryor Creek Formation (Mayes Group) is also equivalent to the St. Louis Limestone. Conodont data, however, show that not all southern mid-continent St. Louis-equivalent strata were created equal. The Moccasin Bend Formation and Quapaw Limestone, characterized by the co-occurrence the genera *Cavusgnathus* and *Taphrognathus* suggest these strata are equivalent to the lower St. Louis Limestone (REFERENCE). In contrast, the Bayou Manard Member yielded no specimens of *Taphrognathus*, but did yield the first observed occurrence of *Hindeodontoides spicules*. Thus, the Bayou Manard Member is equivalent to the upper St. Louis Limestone (REFERENCES). The Moccasin Bend-Quapaw section is therefore not considered correlative to the Bayou Manard Member at this time.

In chapter IV an attempt was made to define lithologic patterns observed in the Mayes Group in terms of the distribution of depositional facies and infer from that a hierarchy of depositional cyclicity. Previous workers interpreted large-scale shallowing-upward trends within the Mayes Group (Huffman, 1958; Turmelle, 1982), and these depositional trends are recognized throughout northeastern Oklahoma. The Bayou Manard and Lindsey Bridge members of the Pryor Creek Formation appear to represent a single transgressive-regressive depositional cycle, whereas the Ordnance Plant Member is grouped with the Hindsville Formation is a subsequent transgressive-regressive depositional cycle. Separating these two cycles is an unconformity between the Lindsey Bridge and Ordnance Plant members of the Pryor Creek Formation first postulated by Swinchatt (1967), but unrecognized by Huffman (1958). This interpretation also differs from that of Huffman (1958) in that he included Ordnance Plant Member within the other two members of the Pryor Creek Formation in a transgressive-regressive cycle and interpreted the Hindsville Formation by itself as the second cycle. In contrast, Turmelle (1982) interpreted the Mayes Group as a single transgressive-regressive cycle. Both Huffman (1958) and Turmelle (1982) recognized the interfingering of lithofacies typifying the various lithostratigraphic units within the Mayes Group, beyond that of the standard lithostratigraphic succession defined by Huffman. Nothing of significance was attributed to such "interfingering" except that it represented natural mosaic of depositional facies within the overall Mayes Group depositional system. Results of this investigation, however, suggest a more orderly and predictable vertical facies pattern that, along with recognition or re-interpretation of lithostratigraphic boundaries and surfaces, suggest the presence of higher-frequency depositional cycles in the Mayes Group. The implications of multiple orders of depositional cyclicity within the Mayes Group are two-fold. First, Conodont biostratigraphic data provide relative time constraints to these cycles and they are interpreted in terms of the external controlling mechanisms, including early phases of Ouachita tectonism and Late Paleozoic glaciation. Second, because these rocks serve as an analog to equivalent strata in the subsurface of Oklahoma, it may be inferred that those subsurface strata display similar depositional cyclicity, perhaps not as apparent in some instances, and that components of a given petroleum system may be compartmentalized and must be considered by exploration and production geologists.

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APPENDIX A: SYSTEMATIC PALEONTOLOGY

This section concerns the documentation and description of important platform (P1 element) form-species referenced in the papers included in this dissertation. The below information includes selected synonymy, principal diagnostic characteristics, remarks, observed occurrence and range, and material examined for each form-species.

See Appendix B for detailed location-by-location recovery data. Appendix C consists of the measured stratigraphic sections sampled for conodont data and the positions of individual conodont samples taken, with sample designations corresponding to those in the tables of Appendix B. Plates and figures referenced below each species heading references those presented in Appendix D.

Phylum CHORDATA Bateson, 1886

Class CONODONTA Pander, 1856

Division PRIONIODONTIDA Dzik, 1976

Order OZARKODINIDA Dzik, 1976

Suborder OZARKODININA Dzik, 1976

Superfamily POLYGNATHACEA Bassler, 1925

Genus CAVUSGNATHUS (Harris and Hollingsworth, 1933)

Type Species – *Cavusgnathus alta* Harris and Hollingsworth (1933, p. 201, pl. 1, fig. 10a, b)

CAVUSGNATHUS ALTUS (Harris and Hollingsworth, 1933)

Plate 1, Figures D, G, and I

1933 *Cavusgnathus alta* HARRIS AND HOLLINGSWORTH, p. 201, pl. 1, fig. 10.

1941 *Cavusgnathus cristata* Branson and Mehl, p. 177, pl. 5, figs. 26-31.

1953 *Cavusgnathus cristata* Branson and Mehl; Hass, p. 77; pl. 14, figs. 12-14.

1976 *Cavusgnathus altus* (Harris and Hollingsworth); Norby, p. 77, pl. 1, figs. 10, 11, 13, 14.

1980 *Cavusgnathus altus* (Harris and Hollingsworth); Tynan, p. 1296, pl. 2, fig. 26.

1984 *Cavusgnathus cristatus* Branson and Mehl; Austin and Davies, p. 225, pl. 2, fig. 28.

Diagnosis – Narrow asymmetric P1 element in which the free blade joins the platform on the right (outer) side in both left and right elements. Denticulation of the free blade is irregular. Median trough is deep and broad, generally U-shaped, and bordered by ridge-like parapets consisting of transverse ridges. Blade is short and makes up one-third to one-half of the total platform length.

Remarks – The key diagnostic feature of this species is the irregular oral outline of the free blade (irregular denticulation). *Cavusgnathus cristata* is considered a junior synonym to *Cavusgnathus altus*.

Range and Occurrence – Upper Meramecian through middle Chesterian. Recovered from the Moccasin Bend Formation and Pryor Creek Formation of northeastern Oklahoma and the Hindsville Formation in northeastern Oklahoma, southwestern Missouri, and northern Arkansas.

Material – 200 specimens from 21 sections.

CAVUSGNATHUS CHARACTUS (Rexroad, 1957)

Plate 1, Figures A and H

1957 *Cavusgnathus characta* REXROAD, p. 15, pl. 1, fig. 1

1963 *Cavusgnathus characta* Rexroad; Rexroad and Collinson, p. 8, pl. 1, fig 29.

1969 *Cavusgnathus charactus* (Rexroad); Rhodes et al., p. 79, pl. 13, figs. 6a-7d, 13a-c.

1969 *Cavusgnathus character* Rexroad; Thompson and Goebel, p. 22, pl. 1, figs. 1, 4, and 7.

Diagnosis – Identification of this species is based on the characteristic notch present at the intersection of the anterior free blade and platform consisting of ridge-like parapets paralleling a deep median trough. Outer parapets is convex away from the median trough, whereas the inner parapet may be straight to slightly convex away from median trough. Free blade consists of six to eight denticles of mostly equal size, fused almost to their apices. Free blade is generally straight in oral view. Platform may narrow considerably anteriorly. Free blade constitutes approximately one-third of the total length of a given specimen. Carina may extend into the posterior portion of the trough as a series of nodes.

Range and Occurrence – Ranges from lower-upper Meramecian through middle Chesterian. Recovered from the Mayes Group in Oklahoma, Missouri, and Arkansas, and the Moccasin Bend Formation and Quapaw Limestone of the Oklahoma portion of the Tri-State Mining District.

Material – 294 specimens from 22 sections.

CAVUSGNATHUS CONVEXA (Rexroad, 1957)

Plate 1, Figure E

1957 *Cavusgnathus convexa* REXROAD, p.17, pl. 1, figs. 3-6.

1958 *Cavusgnathus convexa*; Rexroad, p. 16, figs. 12-14.

1964 *Cavusgnathus convexa* Rexroad; Rexroad and Furnish, p. 670, pl. 111, fig. 1.

1969 *Cavusgnathus convexus*; Rhodes et al., p. 80, pl. 14, figs 2a-d.

1969 *Cavusgnathus convexa*; Thompson and Goebel, p. 22, pl. 1, figs. 14, 18, 20, and 21

Diagnosis – Asymmetric P1 form species with an orally convex shape of the free blade consisting of four to six fused denticles and making up one-third or less of the total element length. The highest denticle is typically in or near the middle and denticle height decreases both anteriorly and posteriorly. Platform is long and narrow with generally straight (in oral view) ridge-like parapets paralleling a deep trough. In lateral view, parapets are slightly convex orally ("upward"), becoming more so posteriorly.

Remarks – One of two species now commonly included as a morphotype of *Cavusgnathus unicornis* (Kurka, 1997).

Range and Occurrence – Ranges from lower-upper Meramecian through the middle Chesterian. Recovered from Mayes Group in Oklahoma, Arkansas, and Missouri, as well as both the Moccasin Bend Formation and Quapaw Limestone in northeastern Oklahoma (Tri-State Mining District).

Material – 355 specimens from 23 sections.

CAVUSGNATHUS REGULARIS (Youngquist and Miller, 1949)

Plate 1, Figure F

1949 *Cavusgnathus regularis* YOUNGQUIST AND MILLER, p. 619, pl. 101, figs. 24-25.

1963 *Cavusgnathus regularis* Youngquist and Miller; Rexroad and Collinson, p. 9, pl. 1, fig. 28.

1964 *Cavusgnathus regularis* Youngquist and Miller; Rexroad and Furnish, p. 670, pl. 111, fig. 2.

1969 *Cavusgnathus regularis* Youngquist and Miller; Thompson and Geobel, p. 22, pl. 1, figs. 3 and 12.

Diagnosis – Short, stout, asymmetrical P1 element. Short free blade consisting of five to six fused denticles is attached to the outer side of platform. Denticles of blade decrease in size anteriorly, in a regular progression, or are of generally equal size. Medial trough along platform is deep. In lateral view, this form species is commonly convex orally ("upward").

Remarks – Another species that is now considered by some as a morphotype of *Cavusgnathus unicornis* (Kurka, 1997)).

Range and Occurrence – Ranges from lower-upper Meramecian through middle Chesterian. Recovered from Moccasin Bend Formation and Quapaw Limestone of northeastern Oklahoma (Tri-State Mining District). Recovered also from the Mayes Group in Oklahoma, Missouri, and Arkansa.

Material – 431 specimens from 24 sections.

CAVUSGNATHUS UNICORNIS (Youngquist and Miller, 1949)

Plate 1, Figures B and C

1949 *Cavusgnathus unicornis* YOUNGQUIST AND MILLER, p. 619, p. 101, figs. 18-23.

1958 *Cavusgnathus unicornis* Youngquist and Miller; Rexroad, p. 17, pl. 1, figs. 6-11.

1963 *Cavusgnathus unicornis* Youngquist and Miller; Rexroad and Collinson, p. 9, pl. 1, figs. 26-27.

1969 *Cavusgnathus unicornis* Youngquist and Miller; Thompson and Geobel, p. 23, pl. 1, figs. 2, 5, 6, and 8.

Diagnosis – Narrow, gently bowed, asymmetrical P1 element with deep medial trough and free blade attached always on the right (outer) side on both dextral and sinistral elements. Posterior denticle of the free blade is significantly larger (“horn-like”) than other denticles and is inclined posteriorly. In addition to the prominent denticle, the free blade consists of 5 to 6 closely-spaced denticles fused nearly to their apices. Blade is approximately one-third of the total length of a given specimen.

Range and Occurrence – Ranges from lower-upper Meramecian through middle Chesterian strata. Recovered from Moccasin Bend Formation and Quapaw Limestone in the Tri-State Mining District (Oklahoma portion), as well as both the Pryor Creek Formation, and Hindsville Formation of the Mayes Group in Oklahoma, Missouri, and Arkansas. Samples, section/location, age, zone

Material – 1,359 specimens from 24 sections.

Genus GNATHODUS Pander, 1856

Type Species – *Gnathodus mosquensis* Pander 1856, p. 33, pl. 2A, figs. 10a, b, c

Polygnathus bilineatus Roundy, 1926 (From Nemyrovska, 2005 citing Tubbs, 1986)

GNATHODUS BILINEATUS (Roundy, 1926)

Plate 2, Figures A through G

1926 *Polygnathus texanus* ROUNDY, n. sp., p. 21, pl. 3, fig. 10.

1953 *Gnathodus texanus* (Roundy); Hass, p. 80, pl. 14, figs. 15-21.

1957 *Gnathodus modocensis* Rexroad, p. 30, pl. 1, figs. 15-17.

1964 *Gnathodus bilineatus modocensis* Rexroad; Rexroad and Furnish, p. 670, pl. 111, figs. 4, 5.

Diagnosis – Asymmetric P1 form element. Elements are straight to slightly curved inward. Outer platform is broad and ornamented with multiple nodes that may be randomly distributed or organized in concentric rows paralleling the edge of the outer platform. Inner platform consists of a ridge-like parapet that generally parallels the carina, but turns inward and intersects carina at or near posterior end of carina. Ridge-like parapet separated from carina by a narrow to broad, shallow valley consisting of transverse ridges.

Remarks – Morphologic variations within this platform form species were noted by Rhodes et al. (1969) and Lane and Straka (1974) and may or may not have stratigraphic value. Within this study two morphologic variations were recognized and appear to have at least limited stratigraphic value. Morphotype 1 is distinguished based on the less organized ornamentation on the outer platform, narrower inner platform, and deeper trough between inner platform parapet and carina. Morphotype 2, however, consists of more organized and concentric nodal ornamentation on outer platform that tends to extend to the anterior and posterior margins of the outer platform. Morphotype 2 also has a broader inner platform with shallower trough. The inner platform on morphotype 2 is also convex outward.

Range and Occurrence – This species marks the base of the Chesterian series in North America. The species ranges throughout the Chesterian and last occurs in the Pitkin Limestone (Thompson, 1972). In this study, *Gnathodus bilineatus* morphotype 1 was recovered from the Ordnance Plant

Member of the Pryor Creek Formation in northeastern Oklahoma and Hindsville Formation of Oklahoma, Arkansas, and Missouri. Morphotype 2 was only recovered from the Hindsville Formation.

Material – 156 specimens from 17 sections.

GNATHODUS GIRTYI GIRTYI (Hass, 1953)

Plate 3, Figures A through J

1953 *Gnathodus girtyi* HASS, p. 80, pl. 14, figs. 22-24.

1956 *Gnathodus girtyi* (Hass); Elias, p. 118, pl. III, figs. 30-31.

1957 *Gnathodus girtyi* (Hass); Bischoff, p. 24, pl. 4, figs. 17, 22, 23.

1969 *Gnathodus girtyi* girtyi (Hass); Rhodes et al., p. 98-99, pl. 17, figs. 9-10.

1980 *Gnathodus girtyi* girtyi (Hass); Tynan, p. 1302, pl. 1, figs. 9, 16-19.

1996 *Gnathodus girtyi girtyi* (Hass), Skompski, pl. 1, figs. 8, 9.

2005 *Gnathodus girtyi girtyi* (Hass); Nemyrovska, p. 36-37, pl. 7, fig. 15.

Diagnosis –Straight to slightly curved (in oral view) P1 element with asymmetric platform. Inner platform is narrow, whereas the outer platform is somewhat larger. Both the inner and outer platforms are characterized by prominent ridge-like parapets parallel characterized by transverse ridges. Both parapets are concave to the carina and taper posteriorly where they merge with the carina. The ridge on the inner side tends to extend farther posteriorly than does the outer platform ridge. In lateral view, the platform is low and aboral edge (base) of the element is concave aborally (downward). Free blade is approximately one-half of the total length of a given specimen and consists of denticles fused to about halt their height. In many of the specimens examined in this study, the carina ends anterior to the intersection of the two ridge-like parapets.

Range and Occurrence – Chesterian. Recovered from the Lindsey Bridge and Ordnance Plant members (Pryor Creek Formation) and Hindsville Formation of the Mayes Group.

Material – 276 specimens from 16 sections.

GNATHODUS LINGUIFORMIS (Branson and Mehl, 1941a)

Plate 4, Figures H and J

1941a *Gnathodus linguiformis* BRANSON AND MEHL, n. sp., p. 183, pl. 6, figs. 18-26.

2013 *Gnathodus linguiformis* Boardman et al., pl. 15, fig. 4.

Diagnosis – For original diagnosis see Branson and Mehl (1941a). Asymmetric P1 form species. Long free blade making up more than one-half of total length of a given specimen and consisting of denticles fused approximately to their apices. Carina is inflated or expanded posteriorly, described by Branson and Mehl (1941a) as "tongue-like".

Remarks – Commonly considered a morphotype and junior synonym of *Gnathodus texanus* (Hass, 1953; Rexroad and Collinson, 1965). Specimens of *Gnathodus linguiformis* share similarities with some morphologic variations of *Gnathodus pseudosemiglaber*. Assignment of specimens to the form species *Gnathodus linguiformis* is therefore tentative, but differentiation between them and those assigned to Gnathodus texanus and *Gnathodus pseudosemiglaber* seems plausible given the identification of potential new species or subspecies within *Gnathodus texanus* as presented in Boardman et al. (2013).

Range and Occurrence – Ranges within the lower Meramecian. Recovered from the Ritchey Formation and Tahlequah Limestone.

Material – 134 specimens from 10 sections.

GNATHODUS PSEUDOSEMIGLABER (Thompson and Fellows, 1970)

Plate 4, Figs A through G, and I

1970 *Gnathodus texanus pseudosemiglaber* THOMPSON AND FELLOWS, n. subsp., p. 88, pl. 2 figs. 6, 8, 9, 11-13.

1973 *Gnathodus texanus pseudosemiglaber* (Thompson and Fellows); Butler, p. 500, pl. 56, figs. 28, 29, and 36.

1980 *Gnathodus pseudosemiglaber* (Thompson and Fellows); Lane et al., p. 132, pl. 4, figs. 15-17, 19; pl. 5, figs. 8-15; pl. 6, fig. 14.

2013 *Gnathodus psuedosemiglaber* (Thompson and Fellows); Boardman et al., pl. 15, figs. 1-3, 6.

Diagnosis – P1 element with long anterior free blade that generally intersects the broad asymmetric platform in a central location. Blade makes up at least half of the element length. Inner platform is small and narrow with a single prominent node or row of nodes fused to form a high parapet parallel to subparallel to, and slightly curved toward, the carina. Outer platform is broader than the inner platform and also contains one or more nodes typically located close to the carina. Carina is inflated posteriorly, extends past the platform, and consist by parallel rows of straight to anteriorly-curved transverse ridges. See Thompson and Fellows (1970) for original definition.

Range and Occurrence – Middle Visean (Osagean through basal Meramecian) in Oklahoma, Missouri, Kansas, and Arkansas; Boone Group; Reeds Spring Formation, Bentonville Formation, Ritchey Formation, and Tahlequah Limestone.

Material – 928 specimens from 16 sections.

GNATHODUS TEXANUS (Roundy, 1926)

Plate 5, Figures A through H

Plate 6, Figures A through L

1926 *Gnathodus texanus* ROUNDY, n. sp., p. 12, X, pl. 2, figs. 7-8.

1926 *Gnathodus texanus* var. *bicuspidus* ROUNDY, p. 12, pl. 2, fig 9a, b.

1953 *Gnathodus texanus* (Roundy); Hass, p. 80, pl. 14, figs. 15-21.

1965 *Gnathodus texanus* (Roundy); Collinson and Rexroad, p. 8, pl. 1, figs. 33-38.

1980 *Gnathodus texanus* (Roundy); Lane et al., p. 133, pl. 6, figs. 8, 9, 11, 12, 16

1980 *Gnathodus texanus* (Roundy); Tynan, pl. 1, figs. 14, 15.

Diagnosis –P1 element with a long free blade that intersects the asymmetric platform centrally. Outer platform ranges from narrow to broad with no ornamentation, one prominent node, or scattered small nodes. Outer may end short of, or extend and taper to, posterior tip. Interior platform is small and narrow with a prominent single node or parapet comprising three fused nodes and that may be straight or curved (concave toward carina). This parapet may be separated from the carina or connected to it by a thin transverse ridge. Inner platform does not extend to posterior tip. Carina may be thin and narrow or inflated posteriorly.

Remarks – As discussed by Boardman et al. (2013), *Gnathodus texanus* has become a plastic taxon due to its application to morphologically-variable gnathodids ranging throughout the Mississippian, although it is originally a Chesterian form. Some of the specimens included within this form species in this study may, with further study, represent different species. *Gnathodus linguiformis* may simply be a morphotype of *Gnathodus texanus*, or, as presented by Boardman et al. (2013), application of *Gnathodus texanus* be too broad.

Range and Occurrence – Osagean through middle Chesterian (middle to late Visean). Recovered from every unit sampled, albeit not in every sample processed.

Material – 1,806 specimens from 27 sections.

GNATHODUS N. SP. 15 AFF. PUNCTATUS (Boardman et al., 2013)

Plate 7, Figures A through G

2013 *Gnathodus* n. sp. 15 aff. punctatus; Boardman et al., pl. 15, fig. 7.

Diagnosis – Elongate P1 element with a long anterior free blade that makes up one-third to one-half of the entire length of a given specimen. The anterior free blade joins the platform in a generally central location. The platform is broad and variably ornamented. The outer platform is broad and ornamented by a series of nodes that may be randomly distributed to organized concentrically and paralleling the edge of the platform. The inner platform consists of randomly-organized nodes, some of which may be larger and higher than others. Outer platform extends farther posteriorly than the inner platform, whereas the inner platform extends further anteriorly.

The carina is expanded posteriorly due to the fusion of carinal denticles with parallel rows of nodes on both the interior and exterior sides.

Remarks – Resembles *Gnathodus punctatus*, except that the ornamentation on the broad outer platform of *Gnathodus punctatus* radiates outward from the carina towards the edges of the platform, differing from the disorganized to concentrically-organized ornamentation of *Gnathodus* n. sp. 15.

Range and Occurrence – Early Meramecian. Ritchey Formation of Oklahoma, Missouri, and Arkansas; Tahlequah Limestone of northeastern Oklahoma.

Material – 72 specimens from 11 sections.

GNATHODUS SP. A

Plate 8, Figures A through M

1970 *Gnathodus texanus pseudosemiglaber* THOMPSON AND FELLOWS, n. ssp.,

1980 *Gnathodus pseudosemiglaber* (Thompson and Fellows); Lane et al., pl. 4, figs. 15-17; pl. 5, figs. 8-15.

1998 *Gnathodus pseudosemiglaber* (Thompson and Fellows); Perri and Spalleta, pl. 1, fig. 14; pl. 2, fig. 12.

2005 *Gnathodus pseudosemiglaber* (Thompson and Fellows); Blanco-Ferrera et al., fig. 6, n. 27.

2007 *Gnathodus bilineatus* (Roundy, 1926); Singh, pl. 6, figs. 5-7 (as primitive morphotype); pl. 6 fig. 4 (as transitional to).

Diagnosis – Small, elongate P1 element in which the anterior free blade makes up one-third to one-half of the total length of a given specimen. Free blade joins platform in central position. Carina extends past posterior end of platform. Platform is generally narrow. Inner platform consist of short ridge-like parapet that extends farther anteriorly than the outer platform. Inner parapet consists of a series of nodes to transverse ridges. Inner platform extends posteriorly, occasionally to the posterior tip of the carina, as a series of nodes that occasionally gives the posterior carina an inflated appearance. Outer platform is narrow and is ornamented by a series of nodes concave to, and merging posteriorly with, the carina.

Remarks – Specimens assigned to this potentially new species resemble those previously defined as *Gnathodus pseudosemiglaber* (Lane et al., 1980; Perri and Spalleta, 1998; Blanco-Ferrera et al., 2005) or transitional to, or as primitive morphotypes of, *Gnathodus girtyi* and *Gnathodus bilineatus* (Nemyrovska, 2005; Singh, 2007). It may still be a morphologic variation of *Gnathodus pseudosemiglaber*, but it is included here as a separate species and awaits further evaluation before it would be officially proposed as a new species. *Gnathodus* sp. A is also morphologically similar to *Gnathodus cuneiformis* (Osagean) and *Gnathodus typicus* (Kinderhookia) in overall shape and development of inner and outer platform ornamentation, but *Gnathodus* sp. A is separated from these two older form species by several conodont zones based on the zonation of Boardman et al. (2013).

Range and Occurrence – Early Meramecian. Recovered predominantly from the Tahlequah Limestone in northeastern Oklahoma, but also from the Ritchey Formation in Oklahoma and Missouri.

Material – 613 specimens from 6 sections.

Genus HINDEODUS (Rexroad and Furnish, 1964)

Type Species – Trichonodella imperfecta Rexroad

HINDEODUS CRISTULA (Youngquist and Miller, 1949)

Plate 9, Figure A through D

1949 *Spathognathodus cristulus* YOUNQUIST AND MILLER, p. 621, pl. 101, figs. 1-3.

1957 *Spathognathodus cristulus* (Youngquist and Miller); Rexroad, p. 38, pl. 3, figs. 16, 17.

1958 *Spathognathodus cristulus* (Youngquist and Miller); Rexroad, p. 25, pl. 6, figs. 3, 4.

1961 *Spathognathodus cristulus* (Youngquist and Miller); Rexroad and Burton, p. 1156, pl. 141, fig. 9.

1964 *Spathognathodus cristulus* (Youngquist and Miller); Rexroad and Furnish, p. 674, pl. 111, fig. 15.

1968 *Spathognathodus cristulus* (Youngquist and Miller); Thompson and Goebel, p. 42, pl. 4, figs. 13, 15.

1973 *Spathognathodus cristulus* (Youngquist and Miller); Merrill, p. 304, pl. 3, fig. 62.

1987 *Hindeodus cristula* (Youngquist and Miller); von Bitter and Plint, p. 358-359, figs. 2.9, 3.11, 3.15, and 3.16.

1990 *Hindeodus cristula* (Younquist and Miller); Rexroad and Horowitz, p. 502, pl. 1, figs 21-42.

Diagnosis – A short P1 element with a very short blade comprised of eight to twelve compressed and fused denticles. One or two of the most anterior denticles are the most prominent and remaining denticles gradually angle away from the anterior end in the posterior direction. In oral view the platform is very narrow and symmetric to mildly asymmetric. In lateral view the element is quite arched.

Remarks – Subtle variations in terms of the arch of the aboral surface (in lateral view) and the saize and angle of the largest denticle may simply be intraspecific variation or possible new species. Amount of material recovered, in terms of its stratigraphic distribution, prohibited the evaluation of potentially new species.

Range and Occurrence – Species recovered from Moccasin Bend Formation and Pryor Creek Formation in northeastern Oklahoma and Hindsville Formation in northeastern Oklahoma, southwestern Missouri, and northern Arkansas. See Appendix B for specific details concerning recovery of this species.

Material – 592 specimens from 24 sections.

Genus HINDEODONTOIDES (REXROAD AND MILLER, 1996)

Type Species – Spathognathodus spiculus Youngquist and Miller, 1949

HINDEODOINTOIDES SPICULUS (Youngquist and Miller, 1949)

Plate 9, Figures E through G

1949 *Spathognathodus spiculus* YOUNQUIST AND MILLER, p. 622, pl. 101, fig. 4.

1957 *Spathognathodus spiculus* (Youngquist and Miller); Rexroad, p. 38, pl. 3, figs. 18-21.

1958 *Spathognathodus spiculus* (Youngquist and Miller); Rexroad, p. 25, pl. 6, figs. 5-7.

1964 *Spathognathodus spiculus* (Youngquist and Miller); Rexroad and Furnish, p. 674, pl. 111, figs. 20-22.

1968 *Spathognathodus spiculus* (Youngquist and Miller); Thompson and Goebel, p. 43, pl. 4, fig. 12.

1973 *Spathognathodus spiculus* (Youngquist and Miller); Merrill, p. 309, pl. 3, fig. 61.

1996 *Hindeodontoides spiculus* (Youngquist and Miller); Rexroad and Merrill, p. 230-231, figs. 6: 7, 8-17.

Diagnosis – Short P1 element with short anterior free blade that joins the very narrow platform in a central position. Posterior denticles arched orally are separated from the anterior denticles of the free blade by a low area along the oral margin of the element. Posterior free blade consists of two to four denticles that are larger and more prominent than those in farther posterior.

Range and Occurrence – Uppermost Meramecian through middle Chesterian. Recovered from the Pryor Creek Formation in northeastern Oklahoma and the Hindsville Formation in Oklahoma, Missouri, and Arkansas.

Material – 383 specimens from 15 sections.

Genus LOCHRIEA Scott, 1942

Type Species – Lochriea montanaensis Scott, 1942; *Spathognathodus commutatus* Branson and Mehl, 1941b

Diagnosis – P1 elements of short to moderate length with a posterior free blade that intersects the platform in a central location. Platform ranges from narrow to moderately broad, symmetric to mildly asymmetric, round to oval, and unornamented to ornamented.

LOCHRIEA COMMUTATA (Branson and Mehl, 1941b)

Plate 10, Figures L through R

1941b *Spathognathodus commutatus* BRANSON AND MEHL, p. 98, pl. 19, figs. 1-4.

1942 *Lochriea montanaensis* Scott, p. 298, pl. 37, figs 1-7, pl. 38, figs. 1-4, 6, 7, 10, 12.

1953 *Gnathodus inortatus* Hass, n. sp., p. 80, pl. 14, figs. 9-11.

1964 *Gnathodus commutatus* (Branson and Mehl), Rexroad and Furnish, p. 671

1974 *Gnathodus commutatus commutatus* (Branson and Mehl); Lane and Straka, p, 77, fig. 37 (1-9) and fig. 40 (15-18, 23-26).

1976 *Lochriea commutatus* (Branson and Mehl); Norby, p. 143, pl. 13, figs. 1-3, pl. 14, fig. 3-9

1990 *Lochriea commutata* (Branson and Mehl); Rexroad and Horowitz, p. 535, pl. 2, figs. 10-24

1990 *Lochriea commutata* (Branson and Mehl), Whiteside and Grayson, p. 1, figs. 1, 2.

1994 *Lochriea commutata* (Branson and Mehl), von Bitter and Norby, p. 861-869, figs. 2-7.

Diagnosis – Generally short P1 element with a posteriorly-positioned symmetrical to slightly asymmetrical, round to oval unornamented platform. Platform may be flared to very narrow, not extending much past the width of the carina laterally. Free blade, which makes up one-half to two-thirds of the element, joins the platform centrally. The carina is inflated and extends to the posterior tip. In oral view, specimens may be straight to slightly concave inward, especially at the posterior tip in some specimens. In lateral view, specimens appear somewhat rectangular and are straight to slightly convex orally, typically bowing aborally at the posterior end. Denticles are almost completed fused and of equal height along the length of the carina and free blade. Microstructure of denticle apices display a polygonal pattern.

Remarks – The genus *Lochriea* is quite important in biostratigraphic studies in Europe and Asia. Many of the form species range much earlier than their first appearances in North America. *Lochriea commutata* and *Lochriea homopunctatus* first occur just above the Tournaisian-Viséan boundary within the Viséan type area (Hance et al., 2006; Nemyrovska et al., 2006).

Range and Occurrence – In North America, *Lochriea* commutata first appears at or near the base of the Chesterian along with *Gnathodus bilineatus* and extends throughout the Chesterian. In this study this form species was recovered from the Lindsey Bridge Member, Lindsey Bridge Type Locality, Mayes County, Oklahoma. Ordnance Plant Member, Spring Creek Recreation Area Reference Locality and Earbob Recreation Area Reference Locality, Mayes County, Oklahoma. Hindsville Formation

Material – 138 specimens from 16 sections.

LOCHRIEA HOMOPUNCTATUS (Ziegler, 1960)

Plate 10, Figures A through I

1960 *Gnathodus homopunctatus* ZIEGLER, p. 39, pl. 4, fig. 3.

1975 *Paragnathodus homopunctatus* (Ziegler); Higgins, p.

1983 *Pseudognathodus homopunctatus* (Ziegler); Park, p. 132-135, pl. 4, figs. 27-33.

1986 *Gnathodus hompopunctatus* Ziegler; Belka and Groessens, pl. 7, figs. 11-15.

1998 *Pseudognathodus homopunctatus* (Ziegler); Perri and Spalletta, pl. 2, figs. 6, 7, 13.

2005 *Pseudognathodus homopunctatus* (Ziegler); Nemyrovska, p. 45, pl. 7, figs. 2, 3.

2012 *Lochriea homopunctatus*; Atakul-Ozdemir et al., p. 1281, figs. 2A-2F (Pa elements)

Diagnosis – Short P1 element with anterior free blade intersecting platform centrally. Element as a whole is straight or curved inward. Platform is generally symmetrical to sub-symmetrical, oval, and ornamented. Ornamentation occurs on both the inner and outer platform and typically consists of small nodes generally organized into rows that are parallel to sub-parallel to the carina, but are angled toward the carina in the posterior direction. Denticles on free blade are generally equal in size, compressed, and fused halfway to their apices. Denticles of the posterior portion of the carina are similar to those of the blade, but curve aborally in lateral view. Separating the denticles of the free blade and posterior carina are three or four smaller denticles which form an "indention" of the oral surface in lateral view.

Range and Occurrence – In North America, *Lochriea homopunctatus* first occurs in the Meramecian (Tahlequah Limestone of this study) and extends into the Chesterian. In this study, *Lochriea homopunctatus* was recovered from the Tahlequah Limestone, Bayou Manard Member, Lindsey Bridge Member, and Ordnance Plant Member.

Material – 151 specimens from 17 sections.

LOCHRIEA SP. A

Plate 10, Figure K

Diagnosis – Short P1 element with an anterior free blade comprising one-half of the total length of a given specimen. Free blade joins platform centrally. Platform is oval and symmetrical to slightly asymmetrical. Asymmetry due to slight curvature toward the carina of the margin of the interior platform in the posterior direction. Ornamentation may consist of one to three small, poorly developed nodes on the interior platform. Denticles of free blade and carina are generally equal in size, although they may increase in size anteriorly on the free blade. In lateral view, the oral margin is straight, but arches aborally at the posterior end of the carina. Platform generally extends to the posterior tip.

Remarks – Specimens of *Lochriea sp. A* are similar in many respects to *Lochriea homopunctatus*, but lacks the latter's distinctive platform ornamentation.

Range and Occurrence – Only recovered from the base of the Ordnance Plant Member at 2 locations.

Material – 3 specimens from 2 sections.

LOCHRIEA SP. B

Plate 10, Figure J

Diagnosis – Short P1 element with anterior free blade making up as much as two-thirds of the total length of examined specimens. Free blade joins platform centrally. Platform is round to slightly triangular, tapering posteriorly. Platform is symmetrical to slightly asymmetrical. In oral view, elements are slightly curved inward. Platform ornamentation consists of linear rows of nodes on both the inner and outer platforms, slightly fused together to form incipient short parapets, with that of the inner platform extending farther anteriorly, and appear to curve toward the carina anteriorly, than that of the outer platform. Platform parapet, or node rows, slightly angled toward the carina in the posterior direction. Platform does not quite extend to the posterior tip. Denticles of the free blade are largest, followed by those of the posterior carina. Where the free blade joins the platform, denticles of the free blade and posterior carina are separated by several smaller, less developed denticles.

Remarks – The author is hesitant to declare this a new species. These specimens may simply represent morphologic variation within *Lochriea commutata* or *Lochriea homopunctatus*.

Range and Occurrence – Lower Chesterian. Base of Ordnance Plant Member (Pryor Creek Formation, Mayes Group) from two sections.

Material – 2 specimens from 2 sections.

Genus RHACHISTOGNATHUS (Dunn, 1965)

Type Species – Rhachistognathus prima Dunn, 1966

Diagnosis – Elongate, narrow P1 form genus in which the anterior free blade typically joins the platform on the left side (in oral view with anterior pointed up), although the free blade may be detached from the platform margin and slightly positioned more centrally. Platform is narrow and consists of parallel rows of nodes (denticles) on each side of a shallow medium trough.

Remarks – Unlike the trough-parallel ridge-like parapets of *Cavusgnathus* and *Taphrognathus*, the nodal paralleling the trough of *Rhachistognathus* are not transverse ridges, but rather distinct and sharp denticles.

Range and Occurrence – Species assigned to *Rhachistognathus* are most well-known from Upper Mississippian (Upper Chesterian) and Lower Pennsylvanian (Morrowan) strata (Dunn, 1970; Tynan, 1980).

RHACHISTOGNATHUS sp. B cf. R. MURICATUS

Plate 11, Figures G through R

1972 *Spathognathodus muricatus* (Dunn); Thompson, pl. 1, figs 8-19.

1974 *Rhachistognathus muricatus* (Dunn); Lane and Straka, p. 97, fig. 35: 16, 17, 24, 30, 31.

1980 *Rhachistognathus muricatus* (Dunn); Tynan, p. 1303, p. 1, fig. 27.

1981 *Rhachistognathus lanei* (Dunn); Routh, p. , pl., figs. X.

1996 *Rhachistognathus muricatus* (Dunn); Krumhardt et al., pl. 4, figs. 27-30.

Diagnosis –Elongate P1 element with narrow platform consisting of parallel “ridges” separated by a narrow, shallow median trough. Both the outer and inner ridges consist of sharp denticles or nodes. Free blade is approximately one-half the length of the element and may either join the platform on the left side (morphotype 2) or be discontinuous and centrally location (morphotype 1). Element may be straight or slightly bowed. Platform is narrow and consists of parallel rows of denticles on either side of a narrow and shallow medial trough. Denticles on free blade increase in size anteriorly. Posterior carina in centrally located relative to the platform and may extend slightly into the medial trough.

Remarks – Form element is virtually indistinguishable from *Rhachistognathus muricatus* (Dunn) from which *Rhachistognathus sp. B* is separated by an apparent stratigraphic gap that precludes definitive interpretations of evolutionary lineage. At least two morphotypes are recognized in this study, although both appear to occupy the same stratigraphic range. In morphotype 2 the anterior free blade joins the left margin of the platform, whereas the free blade is discontinuous with the left margin and more centrally located in specimens of morphotype 1.

Range and Occurrence – Lower through middle Chesterian. Examples of this species were recovered from the Lindsey Bridge and Ordnance Plant members of the Pryor Creek Formation, as well as from the Hindsville Formation.

Material – 372 specimens from 17 sections.

Genus TAPHROGNATHUS (Branson and Mehl, 1941a)

Type Species – Taphrognathus varians Branson and Mehl 1941a

TAPHROGNATHUS VARIANS (Branson and Mehl, 1941a)

Plate 1, Figures A through F

1941a *Taphrognathus varians* Branson and Mehl, p. 182, pl. 6, figs. 27-33, 34-40

1963 *Taphrognathus varians* (Branson and Mehl); Rexroad and Collinson, p. 21, p. 1, figs. 18-20, 22.

1992 *Taphrognathus varians* (Branson and Mehl); Purnell, p. 20, pl. 4, figs. 2-15, pl. 5, figs. 1-3.

Diagnosis – Long, narrow P1 element with long anterior free blade that makes one-third to more than one-half of the total length of a given specimen. Free blade, in lateral view, increases in height anteriorly and consists of compressed denticles typically fused to more than halfway to their apices. Longest denticles located at anterior end of the anterior free blade. May also possess a short posterior free-blade. Free blades intersect platform in a central position and extends a very short distance into the platform. Platform consists of a shallow to moderately deep medial trough bordered on the inner and outer sides by parallel to subparallel ridge-like parapets made up of series of transverse ridges. Entire element may be straight or slightly curved inward.

Remarks – This is a species that displays a wide range of morphologic variation that has not previously been divided into species with recognizable stratigraphic utility.

Range and Occurrence – Upper Osagean through lower-upper Meramecian. Recovered primarily from the Ritchey Formation, Moccasin Bend Formation, and Quapaw Limestone in the Tri-State Mining District of Oklahoma and Missouri, as well as from the Tahlequah Limestone in Cherokee County, Oklahoma. A few specimens were recovered from the Bentonville Limestone in Oklahoma, Missouri, and Arkansas.

Material – 474 specimens from 14 sections.

Genus VOGELGNATHUS (Norby and Rexroad, 1985)

Type Species – *Spathodgnathodus campbelli* Rexroad, 1957

Remarks – The genus *Vogelgnathus* was established by Norby and Rexroad (1985) as a multielement taxon which includes in the P1 position *Vogelgnathus campbelli* (Rexroad).

VOGELGNATHUS CAMPBELLI (Rexroad, 1957)

1957 *Spathognathodus campbelli* REXROAD, p. 37, pl. 3, figs. 13-15.

1964 *Spathognathodus campbelli* Rexroad; Rexroad and Furnish, p. 674, pl. 111, figs. 23, 24.

1967 *Spathognathodus campbelli* Rexroad; Globensky, p. 447, pl. 55, figs. 13, 20.

1985 *Vogelgnathus campbelli* Norby and Rexroad, pl. 2, figs. 3-10.

1998 *Vogelgnathus campbelli* (Rexroad); Perri and Spalletta, pl. 2, fig. 15.

2005 *Vogelgnathus campbellis* (Rexroad); Nemyrovska, p. 46, pl. 1, figs. 1, 2, 4, 5, and 9.

Diagnosis – Small, narrow P1 element. Very narrow platform that is relatively unornamented. Anterior free blade makes up one-half of the total length of a given element and joins the platform in a central position. Blade and carina together consist of approximately twenty denticles fused to the midway point of their apices. In lateral view, the anterior tip of the free blade is blunt or square. The carina curves downward (aborally) dramatically at the posterior end. Basal cup angles orally in the posterior end as well.

Range and Occurrence – Chesterian. Only recovered from the Hindsville Formation at the Spring Valley Reference Section in Washington County, Arkansas. Reported to range from the Late Meramecian and throughout the Chesterian.

Material – 2 specimens from 1 section.

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APPENDIX B: CONODONT RECOVERY DATA

ALPENA REFERENCE LOCALITY	BOONE GROUP																							MAYES GROUP						
	Bentonville Formation						Short Creek Oolite Member				Ritchey Formation													Hindsville Formation						
	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12	A-13	A-14	A-15	A-16	A-17	A-18	A-19	A-20	A-21	A-22	A-23	A-24	A-25	A-26	A-27	A-28	A-29	A-30
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																									2			1		3
Cavusgnathus charactus																														
Cavusgnathus convexa																										1	1		1	2
Cavusgnathus regularis																								1	2		2		1	4
Cavusgnathus unicornis																									4			2	1	2
Cavusgnathus sp. indeterminate																								3	6	3	2	4	1	4
Cavusgnathus																								4	14	4	5	7	4	15
Gnathodus bilineatus																									3		2		1	4
Gnathodus girtyi girtyi																									2				1	
Gnathodus linguiformis													1			3			1											
Gnathodus pseudosemiglaber	3		1		3	5					1		2			1			2		2									
Gnathodus texanus	3		4	2		4					2	5	1	3		2			4			4								
Gnathodus n. sp. 15 aff. *punctatus*														1																
Gnathodus sp. A																														
Gnathodus sp. indeterminate																														
Hindeodus cristula																								2	4	1	3	5		1
Hindeodontoides spiculus																								4		2	4	2	1	2
Lochriea commutata																									1			2		
Lochriea homopunctatus																														
Rhachistognathus sp. B																								1	2			3	2	1
Taphrognathus varians																														
TOTAL P1 Elements	6		5	2	3	9					3	5	4	4		6			7	0	2	4		11	26	7	14	19	9	23
P1 Elements/kilogram	3.0		2.5	1.0	1.5	4.5					1.5	2.5	2.0	2.0		3.0			3.5	0.0	1.0	2.0		5.5	13.0	3.5	7.0	9.5	4.5	11.5

BAYOU MANARD TYPE LOCALITY	MAYES GROUP																		
	Pryor Creek Formation																		
	Bayou Manard Member																		
	BMTL-1	BMTL-2	BMTL-3	BMTL-4	BMTL-5	BMTL-6	BMTL-7	BMTL-8	BMTL-9	BMTL-10	BMTL-11	BMTL-12	BMTL-13	BMTL-14	BMTL-15	BMTL-16	BMTL-17	BMTL-18	BMTL-19
Sample Size (kg)	4.0	3.0	4.0	4.0	4.0	3.0	3.0	4.0	3.0	4.0	2.0	3.0	3.0	4.0	3.0	4.0	3.0	3.0	2.0
Cavusgnathus charactus																			
Cavusgnathus convexa																			
Cavusgnathus regularis																			
Cavusgnathus unicornis																			
Cavusgnathus sp. indeterminate							1		1				1				1		
Cavusgnathus							1		1				1				1		
Gnathodus texanus						1				1			1			1	3		
Gnathodus sp. indeterminate									2										
Hindeodus cristula								1	1								1		
Hindeodontoides spiculus																			
Lochriea homopunctatus																			
TOTAL P1 Elements	0	0	0	0	0	1	1	1	4	1	0	0	2	0	0	1	5	0	0
P1 Elements/kilogram	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	1.3	0.3	0.0	0.0	0.7	0.0	0.0	0.3	1.7	0.0	0.0

BICENTENNIAL PARK REFERENCE LOCALITY	BOONE GROUP																			
	Bentonville Formation			Short Creek Oolite		Ritchey Formation								Moccasin Bend Formation						
	BCP-1	BCP-2	BCP-3	BCP-4	BCP-5	BCP-6	BCP-7	BCP-8	BCP-9	BCP-10	BCP-11	BCP-12	BCP-13	BCP-14	BCP-15	BCP-16	BCP-17	BCP-18	BCP-19	BCP-20
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus															1					
Cavusgnathus charactus														5	2	7		4		
Cavusgnathus convexa																2	5			5
Cavusgnathus regularis														4	4	3				
Cavusgnathus unicornis														11	15	12		7		11
Cavusgnathus sp. indeterminate														4	7	6	5			1
Cavusgnathus														24	29	30	10	11		17
Gnathodus linguiformis								1			1	2	1	1						
Gnathodus pseudosemiglaber		1	1				1	5		3	1	8	6	2						
Gnathodus texanus	1	3	3					3	2		1	10	2	11	7	3				
Gnathodus n. sp. 15 aff. *punctatus*											1		1							
Gnathodus sp. A								2		2	1	2	3							
Gnathodus sp. indeterminate																				
Hindeodus cristula																				
Lochriea homopunctatus																				
Taphrognathus varians											1	2		3	1	2		4		
TOTAL P1 Elements	1	4	4				1	11	2	5	6	24	13	41	37	35	10	15		17
P1 Elements/kilogram	0.5	2.0	2.0				0.5	5.5	1.0	2.5	3.0	8.0	3.3	20.5	18.5	17.5	5.0	7.5		8.5

BICENTENNIAL PARK REFERENCE LOCALITY	BOONE GROUP																			
	Moccasin Bend Formation																			
	BCP-21	BCP-22	BCP-23	BCP-24	BCP-25	BCP-26	BCP-27	BCP-28	BCP-29	BCP-30	BCP-31	BCP-32	BCP-33	BCP-34	BCP-35	BCP-36	BCP-37	BCP-38	BCP-39	BCP-40
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus	2																			3
Cavusgnathus charactus		4	1	3	1	1	1			3	2						1			
Cavusgnathus convexa	1			2	2		3		1		4		5			1			5	1
Cavusgnathus regularis	3	3		4	2	2	1			2	2	3				1			1	2
Cavusgnathus unicornis		5			5	3	6	2	4		2		6	6	4	5	5		7	6
Cavusgnathus sp. indeterminate	7	4	2	3	4	6	8	6	5	4	5	4	7	8	5	9	2		8	12
Cavusgnathus	13	16	3	12	14	12	19	8	10	9	15	7	18	14	9	16	8		21	24
Gnathodus linguiformis																				
Gnathodus pseudosemiglaber																				
Gnathodus texanus	9	5			7				6			1		2			1	4		8
Gnathodus n. sp. 15 aff. *punctatus*																				
Gnathodus sp. A																				
Gnathodus sp. indeterminate																				
Hindeodus cristula	5	4				7	3											2		1
Lochriea homopunctatus			1																	1
Taphrognathus varians	3										5	1					2			29
TOTAL P1 Elements	30	25	4	12	21	19	22	8	16	9	20	9	18	16	9	16	11	6	21	63
P1 Elements/kilogram	15.0	12.5	2.0	6.0	10.5	9.5	11.0	4.0	8.0	4.5	10.0	4.5	9.0	8.0	4.5	8.0	5.5	3.0	10.5	31.5

BIDDING CREEK REFERENCE LOCALITY	MAYES GROUP											
	Pryor Creek Formation								Hindsville Formation			
	Ordnance Plant Member											
	BC-1	BC-2	BC-3	BC-4	BC-5	BC-6	BC-7	BC-8	BC-9	BC-10	BC-11	BC-12
Sample Size (kg)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0
Cavusgnathus altus					1				1			1
Cavusgnathus charactus												
Cavusgnathus convexa					3				1	1		1
Cavusgnathus regularis					5				3		2	1
Cavusgnathus unicornis			2		7				5	2	3	4
Cavusgnathus sp. indeterminate					11		1		4	2	6	2
Cavusgnathus			2		27		1		14	5	11	9
Gnathodus bilineatus					3				1	2		1
Gnathodus girtyi girtyi										1		
Gnathodus texanus		2			17							
Hindeodus cristula									3			1
Hindeodontoides spiculus												
Lochriea commutata					8						1	
Lochriea homopunctatus												
Lochriea mononodosus					1?							
Rhachistognathus sp. B											1	
Vogelgnathus campbelli												
TOTAL P1 Elements		2	2		55		1		18	8	13	11
P1 Elements/kilogram		0.7	0.7		18.3		0.3		9.0	4.0	6.5	5.5

BURLINGTON NORTH REFERENCE LOCALITY	BOONE GROUP																												
	Ritchey Formation												Hindsville Formation												Batesville Sandstone				
	BN-1	BN-2	BN-3	BN-4	BN-5	BN-6	BN-7	BN-8	BN-9	BN-10	BN-11	BN-12	BN-13	BN-14	BN-15	BN-16	BN-17	BN-18	BN-19	BN-20	BN-21	BN-22	BN-23	BN-24	BN-25	BN-26	BN-27	BN-28	BN-29
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus														3		2			1	2			1						
Cavusgnathus charactus																1													
Cavusgnathus convexa													1	2	1		4		2			1			1				
Cavusgnathus regularis														2		7	3	1	2		1						2		
Cavusgnathus unicornis													9	11	12	8	23	6	7	3	1		1	13	1		1		
Cavusgnathus sp. indeterminate													14	19	8	15	18	7	4	2			1	3					
Cavusgnathus													24	37	21	33	48	14	16	7	2	1	3	16	2		3		
Gnathodus bilineatus														8			6	1		1				3					
Gnathodus girtyi girtyi																								1					
Gnathodus linguiformis		1					1																						
Gnathodus pseudosemiglaber		2							1			2																	
Gnathodus texanus	1	3		1			1		2	1		5		5			1					3							
Gnathodus sp. A																													
Gnathodus sp. indeterminate																													
Hindeodus cristula														3			8			9		11							
Hindeodontoides spiculus														4			5			2		12							
Lochriea commutata														1								3		2					
Lochriea homopunctatus																													
Rhachistognathus sp. B															2				3			1		2		2			
Taphrognathus varians																													
Taphrognathus sp.		1						1																					
Vogelgnathus campbelli																													
TOTAL P1 Elements	1	7		1			2	1	3	1		7	24	58	23	33	68	15	19	19	2	31	3	24	2	2	3		
P1 Elements/kilogram	0.5	3.5		0.5			1	0.5	1.5	0.5		3.5	12	29	11.5	16.5	34	7.5	9.5	9.5	1	15.5	1.5	12	1	1	1.5		

BURLINGTON SOUTH REFERENCE LOCALITY	BOONE GROUP																				MAYES GROUP								
	Bentonville Formation		Short Creek Oolite Member			Ritchey Formation															Hindsville Formation								
	BS-1	BS-2	BS-3	BS-4	BS-5	BS-6	BS-7	BS-8	BS-9	BS-10	BS-11	BS-12	BS-13	BS-14	BS-15	BS-16	BS-17	BS-18	BS-19	BS-20	BS-21	BS-22	BS-23	BS-24	BS-25	BS-26	BS-27	BS-28	BS-29
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																						6	3	4	1	2	3	2	
Cavusgnathus charactus																								1				5	
Cavusgnathus convexa																						2	3	3	4		1	8	
Cavusgnathus regularis																						5	3	6	2	2	2	11	
Cavusgnathus unicornis																						15	9	13	4	7	5	30	
Cavusgnathus sp. indeterminate																					5	10	6	4	3	6	1	15	
Cavusgnathus																					5	38	24	31	14	17	12	71	
Gnathodus bilineatus																						5	3		2	3		5	
Gnathodus girtyi girtyi																						1	2			2		2	
Gnathodus linguiformis																													
Gnathodus pseudosemiglaber									3	1					1		1		24	26									
Gnathodus texanus	1	1					2	1	4	2		2			3							8	5	4	11	3	1	11	
Gnathodus n. sp. 15 aff. *punctatus*										2																			
Gnathodus sp. A																													
Gnathodus sp. indeterminate																						7	12	7	4	2			
Hindeodus cristula																						16	8	14	11	7		11	
Hindeodontoides spiculus																						11	13	9	6	2	1	31	
Lochriea commutata																						3	1					7	
Lochriea homopunctatus																													
Rhachistognathus sp. B																												1	
Taphrognathus varians						1			1																				
TOTAL P1 Elements	1	1				1	2	1	8	5		2			4		1		24	26	5	89	68	65	48	36	14	139	
P1 Elements/kilogram	0.5	0.5				0.5	1.0	0.5	4.0	2.5		1.0			2.0		0.5		12.0	13.0	2.5	44.5	34.0	32.5	24.0	18.0	7.0	69.5	

CEDAR CREEK REFERENCE LOCALITY	BOONE GROUP																												
	Bentonville Formation				Short Creek Oolite Mbr		Ritchey Formation																						
	CC-1	CC-2	CC-3	CC-4	CC-5	CC-6	CC-7	CC-8	CC-9	CC-10	CC-11	CC-12	CC-13	CC-14	CC-15	CC-16	CC-17	CC-18	CC-19	CC-20	CC-21	CC-22	CC-23	CC-24	CC-25	CC-26	CC-27	CC-28	CC-29
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Gnathodus linguiformis																													
Gnathodus pseudosemiglaber		3		3			2							2									1						
Gnathodus texanus		2					3		2			1		3				1				1	3		2				1
Gnathodus n. sp. 15 aff. *punctatus*							3																						
Gnathodus sp. A																													
Gnathodus sp. indeterminate																						1					1		2
Taphrognathus varians							3							1				2		1									
TOTAL P1 Elements		5		3			11		2			1		6				3		1		2	4		2		1	0	3
P1 Elements/kilogram		2.5		1.5			5.5		1.0			0.5		3.0				1.5		0.5		1.0	2.0		1.0		0.5	0.0	1.5

CHOUTEAU BEND REFERENCE LOCALITY	MAYES GROUP																											
	Pryor Creek Formation			Hindsville Formation																								
	Ordnance Plant Member																											
	CB-1	CB-2	CB-3	CB-4	CB-5	CB-6	CB-7	CB-8	CB-9	CB-10	CB-11	CB-12	CB-13	CB-14	CB-15	CB-16	CB-17	CB-18	CB-19	CB-20	CB-21	CB-22	CB-23	CB-24	CB-25	CB-26	CB-27	CB-28
Sample Size (kg)	4.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus				3	1	2	4	3	5				2		1	2	1								1			1
Cavusgnathus charactus				3			1		2							1												
Cavusgnathus convexa					1	3		5	8				1									1	1		2	3	2	1
Cavusgnathus regularis				2	2	5	5	4	4			1		1	2	2		1				1				1	1	
Cavusgnathus unicornis			1	4	7	6	10	7	11							3	3				3	3			1	4	6	6
Cavusgnathus sp. indeterminate		2		7	2	11	3	15	5		2		2	2	5		1		1				2					
Cavusgnathus		2	1	19	13	27	23	34	35	0	2	1	5	3	8	8	5	1	1		3	5	3		4	8	9	8
Gnathodus bilineatus				2	4		4																					
Gnathodus girtyi girtyi						2																						
Gnathodus texanus				2	3	3	5		4		2					1												
Gnathodus sp. indeterminate																												
Hindeodus cristula					12	5			5	1	2				4	7										24	15	4
Hindeodontoides spiculus					7	6	4		4		8		3	3	4	11							2			20	16	7
Lochriea commutata				1	3				1																			
Rhachistognathus sp. B																												
TOTAL P1 Elements		2	1	24	42	43	36	34	49	1	14	1	8	6	16	27	5	1	1		3	5	5		4	52	40	19
P1 Elements/kilogram		0.5	0.5	12.0	21.0	21.5	18.0	17.0	24.5	0.5	7.0	0.5	4.0	3.0	8.0	13.5	2.5	0.5	0.5		1.5	2.5	2.5		2.0	26.0	20.0	9.5

DEVIL'S PROMENADE REFERENCE LOCALITY	BOONE GROUP — Moccasin Bend Formation																			
	DP-1	DP-2	DP-3	DP-4	DP-5	DP-6	DP-7	DP-8	DP-9	DP-10	DP-11	DP-12	DP-13	DP-14	DP-15	DP-16	DP-17	DP-18	DP-19	DP-20
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus													1							
Cavusgnathus charactus						2		2			1	1		2	1	1			1	
Cavusgnathus convexa						1		2		1	1			1						
Cavusgnathus regularis				1		4	1						3	3	1	3				
Cavusgnathus unicornis		1				5		1	4		3	5	3	9	3	2	1		3	1
Cavusgnathus sp. indeterminate	3	3	2	2	5	4	4	6	2	1		3	5	3			2	3	3	
Cavusgnathus	3	4	2	3	5	16	5	11	6	2	5	9	12	18	5	6	3	3	7	1
Gnathodus texanus	2			5			2		3			1	5			1		1		
Hindeodus cristula		1			3				2		2	1				4			1	
Lochriea homopunctatus				1										1					1	
Taphrognathus varians	1		1		4		1	2		4	1		3	3		1		1		
TOTAL P1 Elements	6	5	3	9	12	16	8	13	11	6	8	11	20	22	5	12	3	5	9	1
P1 Elements/kilogram	3.0	2.5	1.5	4.5	6.0	8.0	4.0	6.5	5.5	3.0	4.0	5.5	10.0	11.0	2.5	6.0	1.5	2.5	4.5	0.5

EARBOB RECREATION AREA REFERENCE LOCALITY	MAYES GROUP — Pryor Creek Formation											
	Bayou Manard Member			Lindsey Bridge Member		Ordnance Plant Member						
	E-1	E-2	E-3	E-4	E-5	E-6	E-7	E-8	E-9	E-10	E-11	E-12
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus						3	2					
Cavusgnathus charactus				1		3	3					
Cavusgnathus convexa					1	4	3					
Cavusgnathus regularis					2	5	6					
Cavusgnathus unicornis		1		3	1	7	16				1	
Cavusgnathus sp. indeterminate		1	1		2	4	7		1		1	
Cavusgnathus		2	1	4	6	26	37		1		2	
Gnathodus bilineatus						3	1					
Gnathodus texanus		2	3	2	1	8	6	2			1	
Gnathodus girtyi girtyi				5	2	7	2					
Gnathodus sp. indeterminate												
Hindeodus cristula				1		2	2				1	
Hindeodontoides spiculus				2		3	1					
Lochriea commutata						1						
Lochriea homopunctatus						5						
Rhachistognathus sp. B				3	2	43	13				2	
Vogelgnathus campbelli												
TOTAL P1 Elements		4	4	17	11	98	62	2	1		6	
P1 Elements/kilogram		2.0	2.0	8.5	5.5	49.0	31.0	1.0	0.5		3.0	

FAIRLAND QUARRY REFERENCE LOCALITY	BOONE GROUP																									MAYES GROUP?									
	Bentonville Formation					Short Creek Oolite		Ritchey Formation																		LAG	Hindsville Formation?								
	FQ-1	FQ-2	FQ-3	FQ-4	FQ-5	FQ-6	FQ-7	FQ-8	FQ-9	FQ-10	FQ-11	FQ-12	FQ-13	FQ-14	FQ-15	FQ-16	FQ-17	FQ-18	FQ-19	FQ-20	FQ-21	FQ-22	FQ-23	FQ-24	FQ-25	FQ-26	FQ-27	FQ-28	FQ-29	FQ-30	FQ-31	FQ-32	FQ-33	FQ-34	FQ-35
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	2.0	2.0	4.0	3.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																																			
Cavusgnathus charactus																																			1
Cavusgnathus convexa																												1				1			2
Cavusgnathus regularis																										2						1			
Cavusgnathus unicornis																										1	1	1	2			2			2
Cavusgnathus sp. indeterminate																										5	2		1	1			3		2
Cavusgnathus																										8	3	2	3	1		4	3		7
Gnathodus bilineatus																																			
Gnathodus girtyi girtyi																													1	1					
Gnathodus linguiformis								4	5	2			4		1	5	1	2	2	4		3	3	4	1										
Gnathodus pseudosemiglaber	1		3	1				3	20	16	4	13	13	15	7	9	10	6	7	2	10	5	6	12	9										
Gnathodus texanus	2			1	2			5	16	14	3	10	8	12	5	11	7	8	9	8	11	9	11	7	5										
Gnathodus n. sp. 15 aff. *punctatus*								2	4	2	1	3	4	1	2	3	2	2	3	1	2		1	3	1										
Gnathodus sp. A								1	4	3	3	4	2	2	2	3	2	3	5	7	1	4	2	4	1										
Gnathodus sp. indeterminate									2			2	3	1	3		2		5	2	3	5		2	3										
Hindeodus cristula																																			
Hindeodontoides spiculus																																			
Lochriea commutata																																			
Lochriea homopunctatus																																			
Rhachistognathus sp. B																													2	1			1		2
Taphrognathus varians								2	16	8	2	5	8	12	3	12	3	6	6	9	5	8	9	3	4										
Taphrognathus sp.										1																									
TOTAL P1 Elements	3		3	2	2			17	67	46	13	37	42	43	23	43	27	27	37	33	32	34	32	35	24	16	3	2	6	3		4	4		9
P1 Elements/kilogram	1.5		1.5	1.0	1.0			8.5	33.5	23.0	6.5	18.5	21.0	21.5	11.5	21.5	13.5	13.5	18.5	16.5	16.0	17.0	16.0	17.5	12.0	10.7	1.5	1.0	1.5	1.0		2.0	2.0		4.5

LINDSEY BRIDGE TYPE LOCALITY	BOONE GROUP		MAYES GROUP													
			Pryor Creek Formation													
			Bayou Manard Member													
	LB-1	LB-2	LB-3	LB-4	LB-5	LB-6	LB-7	LB-8	LB-9	LB-10	LB-11	LB-12	LB-13	LB-14	LB-15	LB-16
Sample Size (kg)	2.0	2.0	3.0	3.0	3.0	3.0	2.0	3.0	2.5	3.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																
Cavusgnathus charactus								1								
Cavusgnathus convexa																
Cavusgnathus regularis																
Cavusgnathus unicornis			2	1								1				
Cavusgnathus sp. indeterminate																
Cavusgnathus			2	1				1				1				
Gnathodus bilineatus																
Gnathodus girtyi girtyi																
Gnathodus pseudosemiglaber	1	1														
Gnathodus texanus	1	2	4	3	1			2	1		1		1		1	
Gnathodus sp. indeterminate																
Hindeodus cristula			1	1												
Hindeodontoides spiculus				2	1				1							
Lochriea commutata																
Lochriea homopunctatus			1	1												
Rhachistognathus sp. B																
TOTAL P1 Elements	2	3	8	8	2			3	2		1	1	1		1	
P1 Elements/kilogram	1.0	1.5	2.7	2.7	0.7			1.0	0.8		0.5	0.5	0.5		0.5	

LINDSEY BRIDGE TYPE LOCALITY	MAYES GROUP																		
	Pryor Creek Formation																		
	Lindsey Bridge Member																		
	LB-17	LB-18	LB-19	LB-20	LB-21	LB-22	LB-23	LB-24	LB-25	LB-26	LB-27	LB-28	LB-29	LB-30	LB-31	LB-32	LB-33	LB-34	LB-35
Sample Size (kg)	2.0	2.0	2.0	2.1	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																	1		
Cavusgnathus charactus													1						1
Cavusgnathus convexa		2														4		8	
Cavusgnathus regularis						1						3	1		2		5		
Cavusgnathus unicornis	4	8				1		1	1		2			1	7	5	3	10	7
Cavusgnathus sp. indeterminate	4	3											2		1	4	6	7	3
Cavusgnathus	8	13				2		1	1		2	3	4	1	10	13	15	25	11
Gnathodus bilineatus																			
Gnathodus girtyi girtyi	1	1		1		2				1	1		1		5	3	1		4
Gnathodus pseudosemiglaber																			
Gnathodus texanus	1	1		1	1	3		1	1		2			1				1	
Gnathodus sp. indeterminate																			
Hindeodus cristula		1									1		2						
Hindeodontoides spiculus		1				1					1		3		2				
Lochriea commutata										1									
Lochriea homopunctatus	1	1				1													
Rhachistognathus sp. B	1	1				1					1					5		3	
TOTAL P1 Elements	12	19		2	1	10		2	2	2	8	3	10	2	17	21	16	29	15
P1 Elements/kilogram	6.0	9.5		1.0	0.5	5.0		1.0	1.0	1.0	4.1	1.5	5.0	1.0	8.5	10.5	8.0	14.5	7.5

LINDSEY BRIDGE TYPE LOCALITY	MAYES GROUP																
	Pryor Creek Formation															Hindsville Formation	
	Ordnance Plant Member																
	LB-36	LB-37	LB-38	LB-39	LB-40	LB-41	LB-42	LB-43	LB-44	LB-45	LB-46	LB-47	LB-48	LB-49	LB-50	LB-51	LB-52
Sample Size (kg)	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0
Cavusgnathus altus																2	
Cavusgnathus charactus																	
Cavusgnathus convexa																2	3
Cavusgnathus regularis																1	
Cavusgnathus unicornis	2	1	1		1				1						1	1	3
Cavusgnathus sp. indeterminate	1		1				1		1							1	2
Cavusgnathus	3	1	2		1		1		2						1	7	8
Gnathodus bilineatus		1														2	1
Gnathodus girtyi girtyi		1				1											2
Gnathodus pseudosemiglaber																	
Gnathodus texanus	1					1			1					1		1	4
Gnathodus sp. indeterminate																	
Hindeodus cristula		1														4	1
Hindeodontoides spiculus									1							2	3
Lochriea commutata																	1
Lochriea homopunctatus		1	1														
Rhachistognathus sp. B		3															1
TOTAL P1 Elements	4	8	3		1	2	1		4					1	1	16	21
P1 Elements/kilogram	1.3	2.7	1.0		0.3	0.7	0.3		1.3					0.3	0.3	8.0	10.5

MOCCASIN BEND TYPE LOCALITY

BOONE GROUP

MOCCASIN BEND TYPE LOCALITY	Bentonville Formation							Short Creek Oolite Member	Ritchey Formation							
	MB-1	MB-2	MB-3	MB-4	MB-5	MB-6	MB-7		MB-8	MB-9	MB-10	MB-11	MB-12	MB-13	MB-14	MB-15
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	**NOT SAMPLED**	2.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0
Cavusgnathus altus																
Cavusgnathus charactus																
Cavusgnathus convexa																
Cavusgnathus regularis																
Cavusgnathus unicornis																
Cavusgnathus sp. indeterminate																
Cavusgnathus																
Gnathodus linguiformis																
Gnathodus pseudosemiglaber	3		1	1			2		1	2	2	2		1	4	2
Gnathodus texanus	2	1	4	1	1	1	1				2	2	1			
Gnathodus n. sp. 15 aff. *punctatus*									1		1	1			1	
Gnathodus sp. A										2	1	1		1	3	2
Gnathodus sp. indeterminate																
Hindeodus cristula																
Lochriea homopunctatus																
Taphrognathus varians									1		x	1			2	
Taphrognathus sp.																
TOTAL P1 Elements	5	1	5	2	1	1	3		3	4	6	7	1	2	10	4
P1 Elements/kilogram	2.5	0.5	2.5	1.0	0.5	0.5	1.5		1.5	1.3	2.0	2.3	0.3	1.0	5.0	2.0

MOCCASIN BEND TYPE LOCALITY	Moccasin Bend Formation																					
	MB-16	MB-17	MB-18	MB-19	MB-20	MB-21	MB-22	MB-23	MB-24	MB-25	MB-26	MB-27	MB-28	MB-29	MB-30	MB-31	MB-32	MB-33	MB-34	MB-35	MB-36	MB-37
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.2	2.0	2.0
Cavusgnathus altus									1													
Cavusgnathus charactus	4	4	5	6	2	7		1	7	3	4	1	2	2		2	1	2	4	2		4
Cavusgnathus convexa	2	1	2	4	1	1	3		4				2				4	1	6			
Cavusgnathus regularis	7	2		1	3	1	1		2				3				2		1			
Cavusgnathus unicornis	10	11	4	6	5	14	4	1	6	1	2	1	11	7	2	1	4	2	4	2	1	4
Cavusgnathus sp. indeterminate	11	3	7	5	4	9	7		12				6		2		2		2			
Cavusgnathus	34	21	18	22	15	32	15	2	32	4	6	2	24	9	4	3	13	5	17	4	1	8
Gnathodus linguiformis																						
Gnathodus pseudosemiglaber																						
Gnathodus texanus	8		7			12		1	22	2	3			2		3		1	1	2		1
Gnathodus n. sp. 15 aff. *punctatus*																						
Gnathodus sp. A																						
Gnathodus sp. indeterminate									1													
Hindeodus cristula	4	2	4			3			4		5		6	2			2	1	3	6		
Lochriea homopunctatus		1					2		1			3		1				1				
Taphrognathus varians	4			4			3		6			2	1					4		1		6
Taphrognathus sp.									1													
TOTAL P1 Elements	50	24	29	26	15	47	20	3	67	6	14	7	31	14	4	6	15	12	21	13	1	15
P1 Elements/kilogram	25.0	12.0	14.5	13.0	7.5	23.5	10.0	1.5	33.5	3.0	7.0	3.5	15.5	7.0	2.0	3.0	7.5	6.0	10.5	5.9	0.5	7.5

MODOT CORE B-49-8	BOONE GROUP																															
	Bentonville Formation											Short Creek Oolite Member		Ritchey Formation																		
	MODOT-1	MODOT-2	MODOT-3	MODOT-4	MODOT-5	MODOT-6	MODOT-7	MODOT-8	MODOT-9	MODOT-10	MODOT-11	MODOT-12	MODOT-13	MODOT-14	MODOT-15	MODOT-16	MODOT-17	MODOT-18	MODOT-19	MODOT-20	MODOT-21	MODOT-22	MODOT-23	MODOT-24	MODOT-25	MODOT-26	MODOT-27	MODOT-28	MODOT-29	MODOT-30	MODOT-31	MODOT-32
Sample Size (kg)	2.0	1.5	2.0	2.0	2.0	1.0	1.0	2.0	1.5	2.0	2.0	2.0	1.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	2.0	1.0	2.0	2.0	1.5	1.0	1.0	1.0	2.0	2.0	1.5	0.5
Gnathodus linguiformis																															3	
Gnathodus pseudosemiglaber																				1			2							2	8	
Gnathodus texanus	3		2			1				1	1	1			1				1	3			2							12	14	
Gnathodus n. sp. 15 aff. *punctatus*																				1												
Gnathodus sp. A																															4	
Gnathodus sp. indeterminate																							1							4		
Lochriea homopunctatus																																
Taphrognathus varians																																
Taphrognathus sp.			1									1		1																		
TOTAL P1 Elements	3		3			1				1	1	2		1	1				1	5			5							18	29	0
P1 Elements/kilogram	1.5		1.5			1.0				0.5	0.5	1.0		1.0	0.5				0.5	2.5			2.5							9.0	19.3	0.0

ORDNANCE PLANT TYPE LOCALITY (LOW WATER DAM)	BOONE GROUP					MAYES GROUP																														
	Bentonville Formation					Pryor Creek Formation																														
						Bayou Manard Member													Lindsey Bridge Member									Ordnance Plant Member								
	LWD-1	LWD-2	LWD-3	LWD-4	LWD-5	LWD-6	LWD-7	LWD-8	LWD-9	LWD-10	LWD-11	LWD-12	LWD-13	LWD-14	LWD-15	LWD-16	LWD-17	LWD-18	LWD-19	LWD-20	LWD-21	LWD-22	LWD-23	LWD-24	LWD-25	LWD-26	LWD-27	LWD-28	LWD-29	LWD-30	LWD-31	LWD-32	LWD-33	LWD-34	LWD-35	LWD-36
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.5	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	3.0	3.0	3.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0	2.5	2.5	3.0	2.5	3.0	3.0	3.0
Cavusgnathus altus																																				
Cavusgnathus charactus						1																														
Cavusgnathus convexa																			1		1		3	1	1	1	1	2					1			
Cavusgnathus regularis							1												1	1		1	2			2				1						
Cavusgnathus unicornis						1	2	1	1		1		1		1				2	2	1		4		1		2	1	1	1		1	1			1
Cavusgnathus sp. indeterminate																										2						1				
Cavusgnathus						2	3	1	1		1		1		1				4	3	2	1	9	1	2	5	3	3	1	2		2	2			1
Gnathodus bilineatus																												1				1				
Gnathodus girtyi girtyi																			1		2		4	1	14		2	1								
Gnathodus pseudosemiglaber	1	1	4	1	1																															
Gnathodus texanus	2	1	3	3	1	2	17	1			3			2	1		1		5	1	1	1	2	1	8	1	1	4	2	1				1		
Gnathodus sp. aff. bulbosus							1																													
Gnathodus sp. indeterminate																																				
Hindeodus cristula							x						1				1		1		1						1	2		2		1				
Hindeodus sp.							1																													
Hindeodontoides spiculus							2	1					2						1		1		3	1		2										
Lochriea commutata																			1										3							
Lochriea homopunctatus							6	1											1				3				1	1				1				
Rhachistognathus sp. B																			1	3			4		5		3	3		1		1				1
TOTAL P1 Elements	3	2	7	4	2	4	30	4	1		4		4	2	2		2		15	7	7	2	25	4	29	8	11	15	6	6		6	2	1		2
P1 Elements/kilogram	1.5	1.0	3.5	2.0	1.0	1.6	15.0	2.0	0.5		2.0		1.3	0.7	0.7		0.7		7.5	3.5	3.5	1.0	12.5	2.0	14.5	4.0	5.5	5.0	2.0	2.4		2.0	0.8	0.3		0.7

PRYOR CREEK TYPE LOCALITY - NORTH HIGH-WALL SECTION	MAYES GROUP																	
	Pryor Creek Formation																	
	Lindsey Bridge Member				Ordnance Plant Member						Hindsville Formation							
	PQN-1	PQN-2	PQN-3	PQN-4	PQN-5	PQN-6	PQN-7	PQN-8	PQN-9	PQN-10	PQN-11	PQN-12	PQN-13	PQN-14	PQN-15	PQN-16	PQN-17	PQN-18
Sample Size (kg)	2.0	2.0	2.0	2.0	3.0	4.0	4.0	4.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus											1	2			2			
Cavusgnathus charactus																		
Cavusgnathus convexa				1									1		5		2	1
Cavusgnathus regularis							1				1		2		3		1	
Cavusgnathus unicornis		1		1							3	3	2	3	5	1	2	
Cavusgnathus sp. indeterminate	2	2	1	1			1	1			2	5	3	2	3	4	2	1
Cavusgnathus	2	3	1	3			2	1			7	10	8	5	18	5	7	2
Gnathodus bilineatus					2						1		2	1			1	
Gnathodus girtyi girtyi	3	1		1	1							1					1	
Gnathodus texanus			1			1			1		1	1					3	
Gnathodus sp. indeterminate											1							
Hindeodus cristula	1		2								2		3	3	1	1		
Hindeodontoides spiculus	2				1		1				1		1	2	2	1		1
Lochriea commutata													1					
Lochriea homopunctatus																		
Rhachistognathus sp. B		2	5	1	2		3	1					1	1				
TOTAL P1 Elements	8	6	9	5	6	1	6	2	1		13	12	16	12	21	7	12	3
P1 Elements/kilogram	4.0	3.0	4.5	2.5	2.0	0.3	1.5	0.5	0.3		6.5	6.0	8.0	6.0	10.5	3.5	6.0	1.5

PRYOR CREEK TYPE LOCALITY - SOUTH HIGH-WALL SECTION	MAYES GROUP													
	Pryor Creek Formation													
	Bayou Manard Member									Member				
	PQS-1	PQS-2	PQS-3	PQS-4	PQS-5	PQS-6	PQS-7	PQS-8	PQS-9	PQS-10	PQS-11	PQS-12	PQS-13	PQS-14
Sample Size (kg)	4.0	4.0	3.0	4.0	4.0	4.0	4.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus														
Cavusgnathus charactus			1							1				
Cavusgnathus convexa														
Cavusgnathus regularis														
Cavusgnathus unicornis										2	1			
Cavusgnathus sp. indeterminate	2									2	1		1	
Cavusgnathus	2		1							5	2		1	
Gnathodus bilineatus														
Gnathodus girtyi girtyi										2	1			
Gnathodus texanus	3	3	2				2					2		1
Hindeodus cristula	1	1									1			
Hindeodontoides spiculus		2									3			
Lochriea commutata														
Lochriea homopunctatus	1										1			
Rhachistognathus sp. B										2	3			
TOTAL P1 Elements	7	6	3				2			9	11	2	1	1
P1 Elements/kilogram	1.8	1.5	1.0				0.5			4.5	5.5	1.0	0.5	0.5

PRYOR CREEK TYPE LOCALITY - SOUTH HIGH-WALL SECTION	MAYES GROUP								
	Pryor Creek Formation								
	Ordnance Plant Member								
	PQS-15	PQS-16	PQS-17	PQS-18	PQS-19	PQS-20	PQS-21	PQS-22	PQS-23
Sample Size (kg)	3.0	2.0	3.0	2.5	3.0	2.5	2.5	3.0	2.0
Cavusgnathus altus									
Cavusgnathus charactus									
Cavusgnathus convexa	1					1	2		
Cavusgnathus regularis									
Cavusgnathus unicornis	1						1		
Cavusgnathus sp. indeterminate	1	2			2	3	2	3	
Cavusgnathus	3	2			2	4	5	3	
Gnathodus bilineatus	2						1		
Gnathodus girtyi girtyi	1						3	1	
Gnathodus texanus			1	1			3	1	
Hindeodus cristula	1			2					
Hindeodontoides spiculus			2				1		
Lochriea commutata			1						
Lochriea homopunctatus	1							1	
Rhachistognathus sp. B	4						3		
TOTAL P1 Elements	12	2	4	3	2	4	16	6	
P1 Elements/kilogram	4.0	1.0	1.3	1.2	0.7	1.6	6.4	2.0	

PRYOR CREEK TYPE LOCALITY - SOUTH HIGH-WALL SECTION	MAYES GROUP													
	Hindsville Formation													
	PQS-24	PQS-25	PQS-26	PQS-27	PQS-28	PQS-29	PQS-30	PQS-31	PQS-32	PQS-33	PQS-34	PQS-35	PQS-36	PQS-37
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus	1	1		1		2			1	1	2	3	2	1
Cavusgnathus charactus				1							1			
Cavusgnathus convexa		1			1								1	
Cavusgnathus regularis	1				1	2			1	1	3	1	2	
Cavusgnathus unicornis	2	2	2	2	3	5	5	1	1		2	1	3	
Cavusgnathus sp. indeterminate	3	5	3	4		3	1		3	2	5	5	3	7
Cavusgnathus	7	9	5	8	5	12	6	1	6	4	13	10	11	8
Gnathodus bilineatus		1		1		2				1	2			
Gnathodus girtyi girtyi	1										1			
Gnathodus texanus	1										2			2
Hindeodus cristula														
Hindeodontoides spiculus	1			2			2		1		2		2	1
Lochriea commutata		1				1		2		1				
Lochriea homopunctatus														
Rhachistognathus sp. B	1										1			
TOTAL P1 Elements	11	11	5	11	5	15	8	3	7	6	21	10	13	11
P1 Elements/kilogram	5.5	5.5	2.5	5.5	2.5	7.5	4.0	1.5	3.5	3.0	10.5	5.0	6.5	5.5

QUAPAW QUARRY REFERENCE LOCALITY	BOONE GROUP																	MAYES GROUP									
	Moccasin Bend Formation				Quapaw Limestone													Hindsville Formation									
	QQ-1	QQ-2	QQ-3	QQ-4	QQ-5	QQ-6	QQ-7	QQ-8	QQ-9	QQ-10	QQ-11	QQ-12	QQ-13	QQ-14	QQ-15	QQ-16	QQ-17	QQ-18	QQ-19	QQ-20	QQ-21	QQ-22	QQ-23	QQ-24	QQ-25	QQ-26	QQ-27
Sample Size (kg)	2.0	4.0	4.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																								1		1	
Cavusgnathus charactus	6	12	5		12	9		1																			
Cavusgnathus convexa	3	6		1	7	2	5	3	2		1			1		1											
Cavusgnathus regularis	8	4	2	2		5				1						2											
Cavusgnathus unicornis	15	2	8	5	11	4	7	2	1	2	1							1								1	
Cavsugnathus sp. indeterminate	7	18	6	4	15	18	17	12	12	5	5			3	2	2	1	1			2		1				1
Cavusgnathus	39	42	21	12	45	38	29	18	15	8	7			4	2	5	1	2			2		1	1		2	1
Gnathodus bilineatus																											
Gnathodus girtyi girtyi																					1	1					
Gnathodus texanus	8	11	6	1	2	2	1	1	1	2	3									1		2			1		
Gnathodus sp. indeterminate																											
Hindeodus cristula	3	8	10	2																							
Hindeodontoides spiculus																											
Lochriea commutata																											
Lochriea homopunctatus	1	6	3	1																							
Rhachistognathus sp. B																		1				1					1
Taphrognathus varians	1	5	3	3	8	17	4	12	6	2	9			2	1	1	1										
Taphrognathus sp.																											
Vogelgnathus campbelli																											
TOTAL P1 Elements	52	72	43	19	55	57	34	31	22	12	19			6	3	6	2	3		1	3	4	1	1	1	2	2
P1 Elements/kilogram	26.0	18.0	10.8	9.5	27.5	28.5	17.0	15.5	11.0	6.0	9.5			3.0	1.5	3.0	1.0	1.5		0.3	1.5	2.0	0.5	0.5	0.5	1.0	1.0

RITCHEY TYPE LOCALITY	BOONE GROUP													
	Bentonville Formation					Short Creek Oolite		Ritchey Formation						
	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9	R-10	R-11	R-12	R-13	R-14
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Gnathodus linguiformis								1				1		
Gnathodus pseudosemiglaber		2			1				4		1	2		1
Gnathodus texanus		5		3	2			5	7		4			3
Gnathodus n. sp. 15 aff. *punctatus*									1		1	1		
Gnathodus sp. A														
Gnathodus sp. indeterminate														2
Taphrognathus varians					1									
Taphrognathus sp.									3		2			1
TOTAL P1 Elements		7		3	4			6	15		8	4		7
P1 Elements/kilogram		3.5		1.5	2.0			3.0	7.5		4.0	2.0		3.5

SELIGMAN REFERENCE LOCALITY	BOONE GROUP																					MAYES GROUP										
	Bentonville Formation																					Hindsville Formation										
	SMO-1	SMO-2	SMO-3	SMO-4	SMO-5	SMO-6	SMO-7	SMO-8	SMO-9	SMO-10	SMO-11	SMO-12	SMO-13	SMO-14	SMO-15	SMO-16	SMO-17	SMO-18	SMO-19	SMO-20	SMO-21	SMO-22	SMO-23	SMO-24	SMO-25	SMO-26	SMO-27	SMO-28	SMO-29	SMO-30	SMO-31	SMO-32
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																									1		1	4	2			
Cavusgnathus convexa																									1		1	2				
Cavusgnathus regularis																												2	1			
Cavusgnathus unicornis																									4	5	2	6	8		2	
Cavusgnathus sp. indeterminate																									19	12	4	12	7	5	14	2
Cavusgnathus																									25	17	8	26	18	5	16	2
Gnathodus bilineatus																										1		2				
Gnathodus pseudosemiglaber						29	35				2		1				2				3											
Gnathodus texanus		2				18	23			2	2		2				8	4		10	2		1			1		2	1			
Gnathodus *sp. indeterminate*		1		1		25	17			1	1		1				2		3		3											
Lochriea commutata																												1				
Lochriea homopunctatus																																
Rhachistognathus sp. B																									1	1		2				
TOTAL P1 Elements		3		1		72	75			3	5		4				12	4	3	10	8		1		26	20	8	33	19	5	16	2
P1 Elements/kilogram		1.5		0.5		36.0	37.5			1.5	2.5		2.0				6.0	2.0	1.5	5.0	4.0		0.5		13.0	10.0	4.0	16.5	9.5	2.5	8.0	1.0

SPRING CREEK RECREATION AREA REFERENCE LOCALITY	MAYES GROUP													
	Pryor Creek Formation													
	Bayou Manard Member					LB*	Ordnance Plant Member							
	SCRA-1	SCRA-2	SCRA-3	SCRA-4	SCRA-5	SCRA-6	SCRA-7	SCRA-8	SCRA-9	SCRA-10	SCRA-11	SCRA-12	SCRA-13	SCRA-14
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	4.0	8.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus							18	2						
Cavusgnathus charactus							6							
Cavusgnathus convexa							29			1				
Cavusgnathus regularis						1	22						1	
Cavusgnathus unicornis		1					32	7		1				
Cavusgnathus sp. indeterminate				1		3	24	18		1			1	
Cavusgnathus		1		1		4	131	27		3			2	
Gnathodus bilineatus							21	3						
Gnathodus girtyi girtyi						6	114	12						
Gnathodus texanus	1			2		1	58	6		1				
Hindeodus cristula							10	3					1	
Hindeodontoides spiculus				1			23	5						
Lochriea commutata						1	4	1						
Lochriea homopunctatus			1			1	16	2						
Lochriea sp. A							3							
Lochriea sp. B							2							
Rhachistognathus sp. B						4	128	22						
TOTAL P1 Elements	1	1	1	4		17	510	81		4			3	
P1 Elements/kilogram	0.5	0.5	0.5	2.0		4.3	63.8	40.5		2.0			1.5	

*LB - Lindsey Bridge Member

SPRING VALLEY REFERENCE LOCALITY	MAYES GROUP																													
	Hindville Formation																													
	SV-1	SV-2	SV-3	SV-4	SV-5	SV-6	SV-7	SV-8	SV-9	SV-10	SV-11	SV-12	SV-13	SV-14	SV-15	SV-16	SV-17	SV-18	SV-19	SV-20	SV-21	SV-22	SV-23	SV-24	SV-25	SV-26	SV-27	SV-28	SV-29	SV-30
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus			2		2		1	1	1	1	3	2	1			2		2	1	3		5		1	3	3	1			2
Cavusgnathus charactus			1	2	1				2			2												2		1	1			
Cavusgnathus convexa	1							4				5		2		1			3			3		1		2				
Cavusgnathus regularis	3		3	3	1			1	5	2	2	6	3	1				1	5		2	2	3			4	3			
Cavusgnathus unicornis	5	4	1	3	4	5	1	7	4	1	5	12	5	2	2	2	4	3	7	6	1	8	2	6	3	2	5	1	1	1
Cavusgnathus *sp. indeterminate*	4	2	5		6		2			4		8	3	1				2				3		2	1	5	1	5	2	1
Cavusgnathus	13	6	12	8	14	5	4	13	12	8	10	35	12	6	2	5	4	8	16	9	3	21	5	12	7	17	11	6	3	4
Gnathodus bilineatus	2	1		1		1			1		1	2			1			3				3	2	4	1		2			
Gnathodus girtyi girtyi												16	8																	
Gnathodus texanus	4		2	1		1		2		3	5	13	9		5	4		2	3		2		1		3		2		1	
Gnathodus sp. indeterminate	1		2		1	1						5			2			1			5		2				3		2	
Hindeodus cristula			2												5						7		4				6		2	
Hindeodontoides spiculus		2	3			3		4				7			6						4									
Lochriea commutata	2		1					1	1	2	9	30	17					2			2		3				2			
Lochriea homopunctatus											2							5												
Rhachistognathus sp. B	2		1					1					3												1				2	
Vogelgnathus campbelli													2																	
TOTAL P1 Elements	24	9	23	10	15	11	4	21	14	13	27	108	51	6	21	9	4	21	19	9	23	24	17	16	12	17	26	6	10	4
P1 Elements/kilogram	12.0	4.5	11.5	5.0	7.5	5.5	2.0	10.5	7.0	6.5	13.5	54.0	25.5	3.0	10.5	4.5	2.0	10.5	9.5	4.5	11.5	12.0	8.5	8.0	6.0	8.5	13.0	3.0	5.0	2.0

STILWELL QUARRY REFERENCE LOCALITY	MAYES GROUP																			
	Pryor Creek Formation																			
	Bayou Manard Member			Lindsey Bridge Member			Ordnan ce Plant Membe		Hindsville Formation											
	SQ-1	SQ-2	SQ-3	SQ-4	SQ-5	SQ-6	SQ-7	SQ-8	SQ-9	SQ-9A	SQ-10	SQ-10A	SQ-11	SQ-12	SQ-13	SQ-14	SQ-15	SQ-16	SQ-17	SQ-18
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus									1	3	1	1	1			2	3	5		2
Cavusgnathus charactus																1			1	2
Cavusgnathus convexa				2		1			2	2	2		3	1		2	1	3		
Cavusgnathus regularis						1	1	1	5	2	1	2	1		1	2	4	1	3	5
Cavusgnathus unicornis	1			5	2	4	1		4	3	4	5	3	3	4	8	2	7	5	
Cavusgnathus sp. indeterminate	2	1		5	3	1			2		3		5		1	2		2	3	6
Cavusgnathus	3	1		12	5	7	2	1	14	10	11	8	13	4	6	17	10	18	12	15
Gnathodus bilineatus								1	3		1			1					1	
Gnathodus girtyi girtyi				5						2			3	2		1				
Gnathodus texanus	3		2	3	1			1	3	1	5		7			1		4	1	
Hindeodus cristula	1			1			3	2	5	2	12	2	5	1		3		5	3	3
Hindeodontoides spiculus	1		1		3		4	1	4	1	4	6	2				3	1	2	
Lochriea commutata				1	1				1			2						1		
Lochriea homopunctatus	2			3																
Rhachistognathus sp. B				7	2	5			2				1							
TOTAL P1 Elements	10	1	3	32	12	12	9	6	32	16	33	18	31	8	6	22	13	29	19	18
P1 Elements/kilogram	5.0	0.5	1.5	16.0	6.0	6.0	4.5	3.0	16.0	8.0	16.5	9.0	15.5	4.0	3.0	11.0	6.5	14.5	9.5	9.0

SYCAMORE CREEK REFERENCE LOCALITY	BOONE GROUP											
	Bentonville Formation					Short Creek Oolite Member		Moccasin Bend Formation				
	SYC-1	SYC-2	SYC-3	SYC-4	SYC-5	SYC-6	SYC-7	SYC-8	SYC-9	SYC-10	SYC-11	SYC-12
Sample Size	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus												
Cavusgnathus charactus								5	2	6	1	1
Cavusgnathus convexa								2		2		
Cavusgnathus regularis								3		4		1
Cavusgnathus unicornis								22	13	3	2	4
Cavusgnathus sp. indeterminate								17	12	4		1
								49	27	19	3	7
Cavusgnathus								49	27	19	3	7
Gnathodus pseudosemiglaber	1		1									
Gnathodus texanus	3		2	1	2			9	4	10	1	2
Gnathodus *sp. indeterminate*								21	2	8		2
Hindeodus cristula									7	7	3	6
Lochriea homopunctatus									2		1	
Taphrognathus varians				1				26	11	3		3
TOTAL P1 Elements	4		3	2	2			105	53	47	8	20
P1 Elements/kilogram	2.0		1.5	1.0	1.0			52.5	26.5	23.5	4.0	10.0

TAHLEQUAH PRINCIPAL REFERENCE LOCALITY	BOONE GROUP																							MAYES GROUP							
	Bentonville Formation					Tahlequah Limestone																	Mixing Zone	Pryor Creek Formation, Bayou Manard Member							
	T-1	T-2	T-3	T-4	T-5	T-6	T-7	T-8	T-9	T-10	T-11	T-12	T-13	T-14	T-15	T-16	T-17	T-18	T-19	T-20	T-21	T-22	T-23	T-24	T-25	T-26	T-27	T-28	T-29	T-30	T-31
Sample Size (kg)	1.5	2.5	2.2	2.3	2.1	0.6	2.0	0.6	2.0	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.6	4.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Cavusgnathus altus																															
Cavusgnathus charactus																													1		
Cavusgnathus convexa																															
Cavusgnathus regularis																							2								
Cavusgnathus unicornis																							7	4					2		
Cavusgnathus sp. indeterminate																							3	7			2		4		
Cavusgnathus																							12	11			2		7		
Gnathodus linguiformis						14	7			4	6		10				13	8	5			3	3								
Gnathodus pseudosemiglaber	2	1	3	1	4	24	36	33	27	21	23	29	24	18	22	17	23	26	16	24	23	11	37								
Gnathodus texanus	1	5	2	2	3	31	54	25	42	31	27	19	25	32	33	24	34	41	34	47	20	27	5	4	2		1		1		
Gnathodus n. sp. 15 aff. *punctatus*															1	1	3	1	2	1											
Gnathodus sp. A						21	47	19	44	42	34	19	32	35	22	24	36	32	44	37	18	19	11								
Gnathodus sp. indeterminate						193	527	233	512	188	137	190	177	217	189	290	335	213	338	393	273	222	37	2		1			4		
Hindeodus cristula																													2		
Hindeodontoides spiculus																															
Lochriea homopunctatus						2	4		2		1	3	1	4		5	2		3	2	3	1	1	2			1				
Taphrognathus varians						2	2	1	4	3	1	2	2	1	1	2	1	1	1	2	2	1	4								
Devonian Form						1																	1								
TOTAL P1 Elements	3	6	5	3	7	288	677	311	631	289	229	262	271	307	268	363	447	322	443	506	339	284	111	19	2	1	4		14		
P1 Elements/kilogram	2.0	2.4	2.3	1.3	3.3	480.0	338.5	493.7	315.5	437.9	369.4	436.7	451.7	548.2	462.1	605.0	709.5	555.2	820.4	790.6	565.0	465.6	27.8	6.3	0.7	0.3	1.3		4.7		

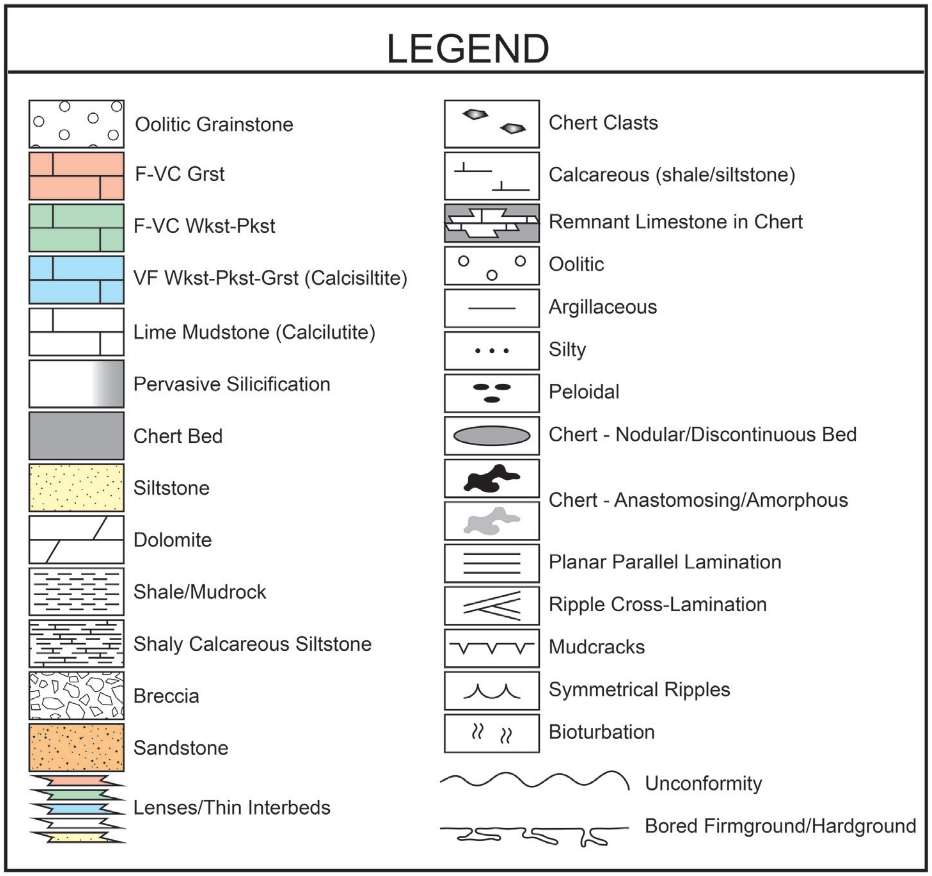
TWIN BRIDGES REFERENCE LOCALITY - SECTION A	BOONE GROUP												
	Short Creek Oolite Member	Ritchey Formation					Moccasin Bend Formation						
	TB1-1	TB1-2	TB1-3	TB1-4	TB1-5	TB1-6	TB1-7	TB1-8	TB1-9	TB1-10	TB1-11	TB1-12	TB1-13
Sample Size (kg)	6.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus													
Cavusgnathus charactus							9	3	5		2	1	
Cavusgnathus convexa								3		2	1	2	
Cavusgnathus regularis							5	3	2	3	2	1	
Cavusgnathus unicornis							10	7	7	7	5	8	
Cavusgnathus sp. indeterminate							13	16	11	5	2	3	
Cavusgnathus							37	32	25	17	12	15	
Gnathodus linguiformis													
Gnathodus pseudosemiglaber		1											
Gnathodus texanus		3		2			6			8		6	
Gnathodus n. sp. 15 aff. *punctatus*		2			3								
Gnathodus sp. A													
Hindeodus cristula							5		7	2			
Lochriea homopunctatus									3			2	
Taphrognathus varians		1		1	2		4		5	4	3	4	
Taphrognathus sp.													
TOTAL P1 Elements		7		3	5		52	32	40	31	15	27	
P1 Elements/kilogram		3.5		1.5	2.5		26.0	16.0	20.0	15.5	7.5	13.5	

TWIN BRIDGES REFERENCE LOCALITY - SECTION B	BOONE GROUP																									
	Bentonville Fm.				Oolite				Ritchey Formation					Moccasin Bend Formation												
	TB2-1	TB2-2	TB2-3	TB2-4	TB2-5	TB2-6	TB2-7	TB2-8	TB2-9	TB2-10	TB2-11	TB2-12	TB2-13	TB2-14	TB2-15	TB2-16	TB2-17	TB2-18	TB2-19	TB2-20	TB2-21	TB2-22	TB2-23	TB2-24	TB2-25	TB2-26
Sample Size (kg)	2.0	2.2	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																	2	1								
Cavusgnathus charactus														6		5	8	3	1	4	2					
Cavusgnathus convexa														2	7	3	2									
Cavusgnathus regularis														4	11		1	3		1		1				
Cavusgnathus unicornis														7	8	18	16	8	4	8	5			1	1	
Cavusgnathus sp. indeterminate														9	15	5	8	7	2	11	1	1			1	2
Cavusgnathus														28	41	31	37	22	7	24	8	2		1	2	2
Gnathodus linguiformis																										
Gnathodus pseudosemiglaber	3	4	5	2					2	3	1	4														
Gnathodus texanus	2	1		5					1	2	1	1	2	5	7	6	6	21		18	1					
Gnathodus n. sp. 15 aff. *punctatus*									1	2		2														
Gnathodus sp. A																										
Hindeodus cristula															6	3	5	5		7	3			1		
Lochriea homopunctatus															3					2						
Taphrognathus varians									3	1	1		2	3	2	1	7	9	2	12		2		1	1	1
TOTAL P1 Elements	5	5	5	7					7	8	3	7	4	36	59	41	55	57	9	63	12	4		3	3	3
P1 Elements/kilogram	2.5	2.3	2.5	3.5					3.5	4.0	1.5	3.5	2.0	18.0	29.5	20.5	27.5	28.5	4.5	31.5	6.0	2.0		1.5	1.5	1.5

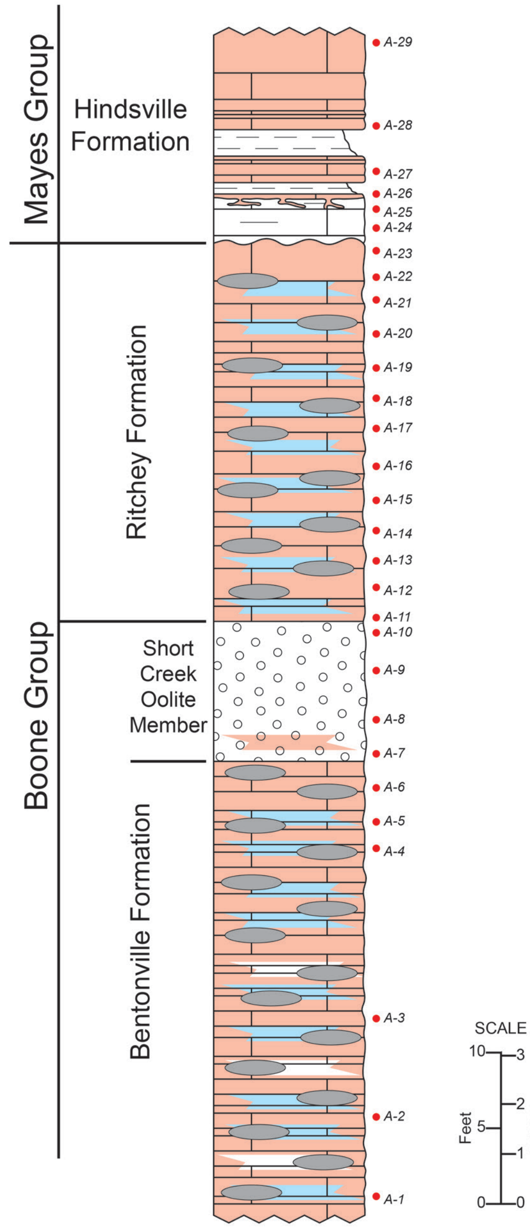
VINITA QUARRY REFERENCE LOCALITY	BOONE GROUP																	
	Moccasin Bend Formation																	
	VQ-1	VQ-2	VQ-3	VQ-4	VQ-5	VQ-6	VQ-7	VQ-8	VQ-9	VQ-10	VQ-11	VQ-12	VQ-13	VQ-14	VQ-15	VQ-16	VQ-17	VQ-18
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus																		
Cavusgnathus charactus	3	1	3	2			2	1		1		2	1		3	1	2	
Cavusgnathus convexa	1	4	1	2				1				1		1	1			1
Cavusgnathus regularis		2	1					2				1	2					
Cavusgnathus unicornis	16	8	9	8	13		5	4	3		2	4	3	1	7	5	3	2
Cavusgnathus sp. indeterminate	12	22	13	14	16		11	8	5	3	3	5	4	4	8	6	4	2
Cavusgnathus	32	37	27	26	29		18	16	8	4	5	13	10	6	19	12	9	5
Gnathodus bilineatus																		
Gnathodus girtyi girtyi																		
Gnathodus texanus	5	13	8	4			5	7		3	5	11	3	4		3		1
Gnathodus sp. indeterminate		5	7	3			4			5				2				3
Hindeodus cristula	5	13	8	7	9					4		5	7		5		3	
Hindeodontoides spiculus																		
Lochriea commutata																		
Lochriea homopunctatus	1	2	1	5			1		3			1		1				2
Rhachistognathus sp. B																		
Taphrognathus varians	2	1	3					2	1			1					1	
TOTAL P1 Elements	45	71	54	45	38	0	28	25	12	16	10	31	20	13	24	15	13	11
P1 Elements/kilogram	22.5	35.5	27.0	22.5	19.0	0.0	14.0	12.5	6.0	8.0	5.0	15.5	10.0	6.5	12.0	7.5	6.5	5.5

VINITA QUARRY REFERENCE LOCALITY	MAYES GROUP											
	Hindsville Formation											
	VQ-19	VQ-20	VQ-21	VQ-22	VQ-23	VQ-24	VQ-25	VQ-26	VQ-27	VQ-28	VQ-29	VQ-30
Sample Size (kg)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Cavusgnathus altus		1			1			3	2	1		2
Cavusgnathus charactus									1			
Cavusgnathus convexa						2					1	
Cavusgnathus regularis					2	3		1	2	1		
Cavusgnathus unicornis	1	2	1	2	3	6	3	5	10	8	4	6
Cavusgnathus sp. indeterminate	2	10	8	2	1	3	5		7		3	5
Cavusgnathus	3	13	9	4	7	14	8	9	22	10	8	13
Gnathodus bilineatus		1	2				2			1		
Gnathodus girtyi girtyi			1				2			2		
Gnathodus texanus	1	1	1		2	2	3			1		
Gnathodus sp. indeterminate						2				1		
Hindeodus cristula			2		4	4			3		6	2
Hindeodontoides spiculus	2		1		3	1	4		5		1	1
Lochriea commutata		2					1			2		
Lochriea homopunctatus												
Rhachistognathus sp. B			1	2	2		3		2	3	5	1
Taphrognathus varians												
TOTAL P1 Elements	6	17	17	6	18	23	23	9	32	20	20	17
P1 Elements/kilogram	3.0	8.5	8.5	3.0	9.0	11.5	11.5	4.5	16.0	10.0	10.0	8.5

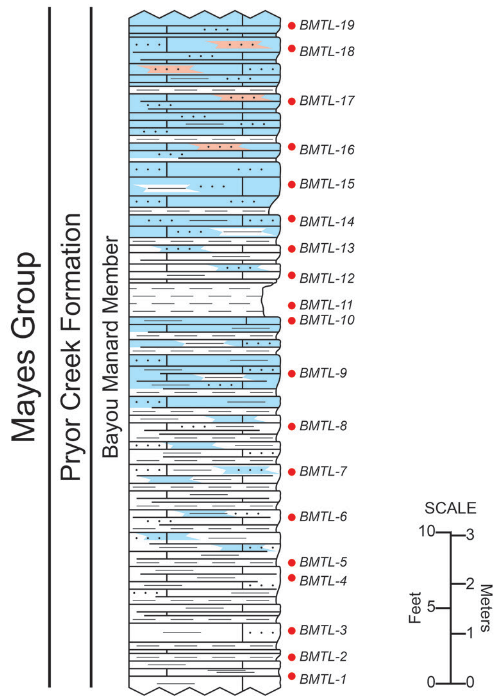
APPENDIX C: MEASURED SECTIONS



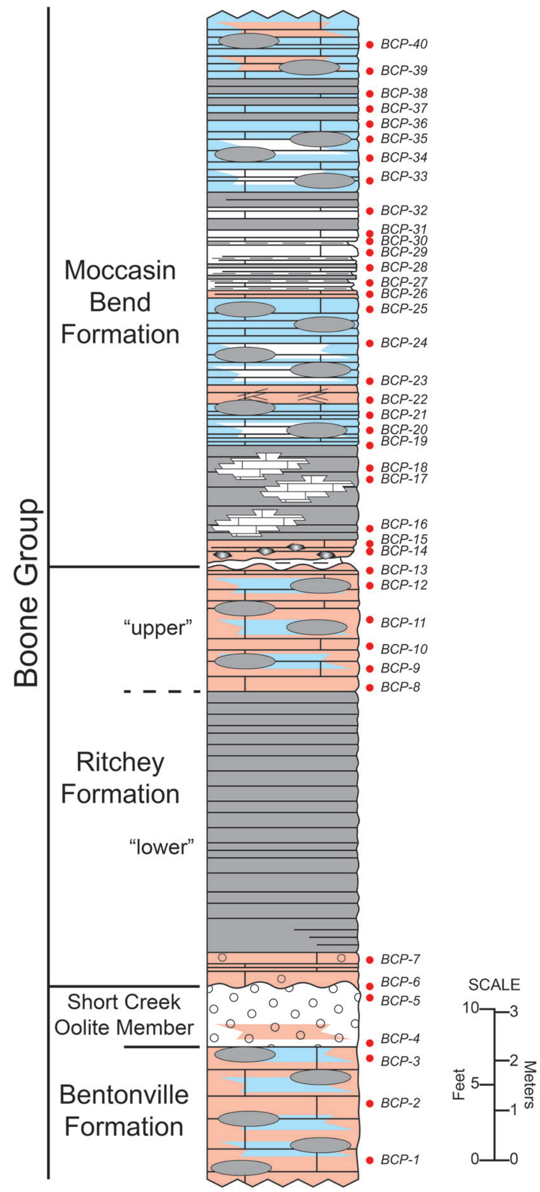
ALPENA REFERENCE SECTION
Boone County, Arkansas
NW NW 22-T19N-R21W



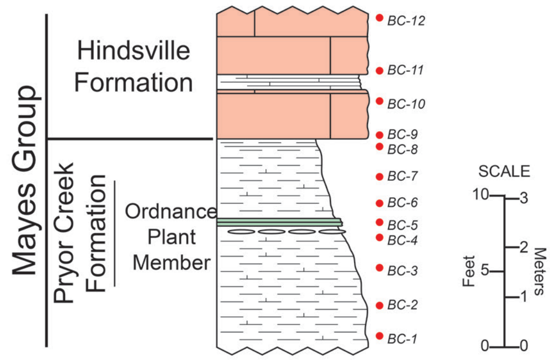
BAYOU MANARD TYPE SECTION
Muskogee County, Oklahoma
C SE 19-T15N-R20E



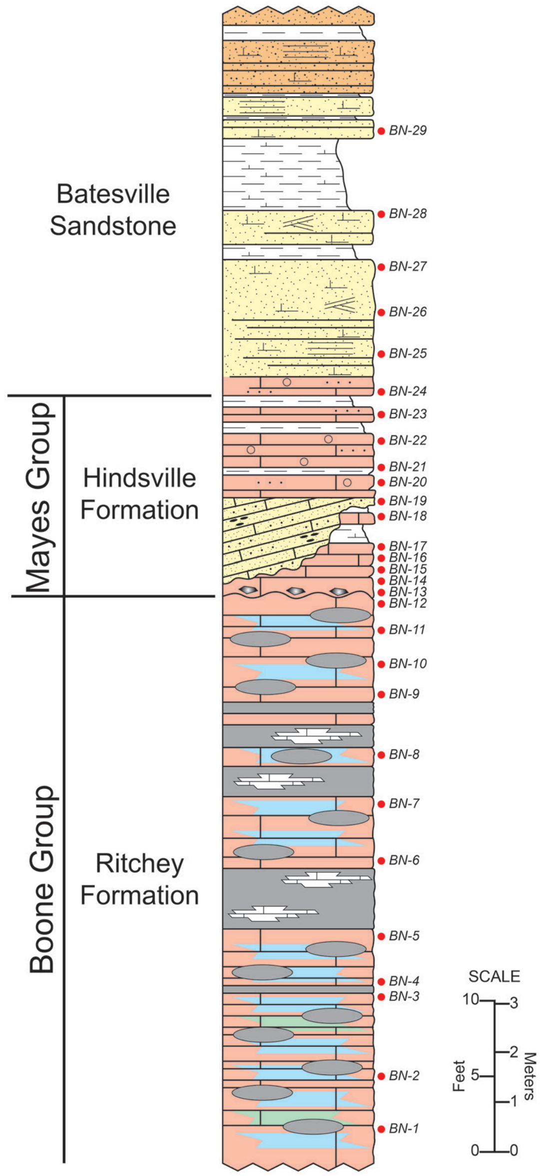
BICENTENNIAL PARK REFERENCE SECTION
Ottawa County, Oklahoma
E SW NE 29-T29N-R24E



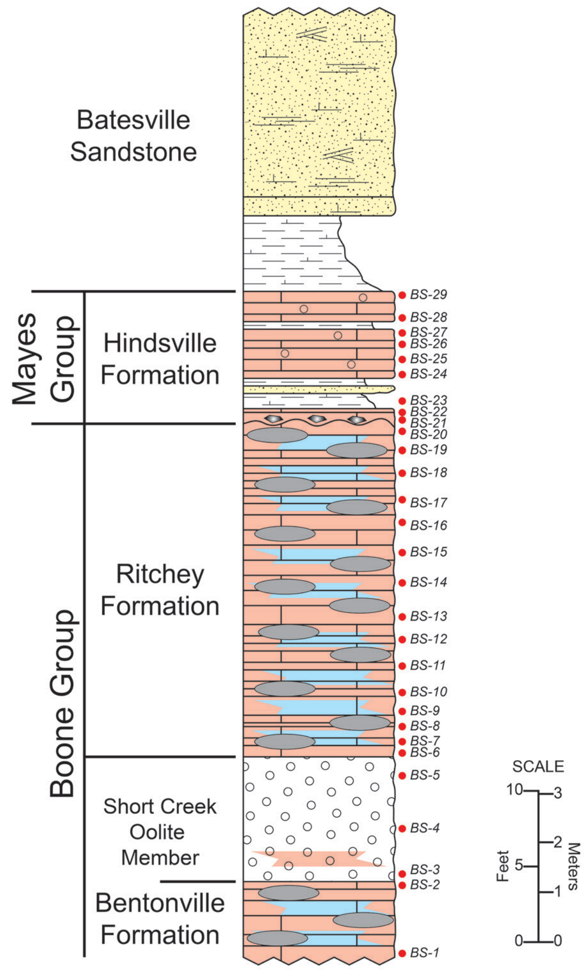
BIDDING CREEK REFERENCE SECTION
Cherokee County, Oklahoma
NE SE NE 17-T16N-R24E



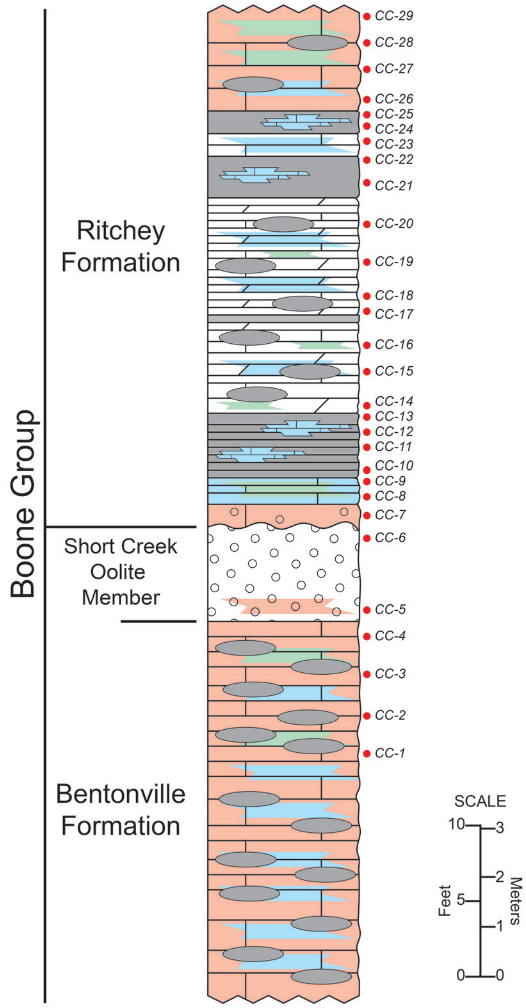
BURLINGTON NORTH REFERENCE SECTION
Boone County, Arkansas
SE NE 20-T20N-R21W

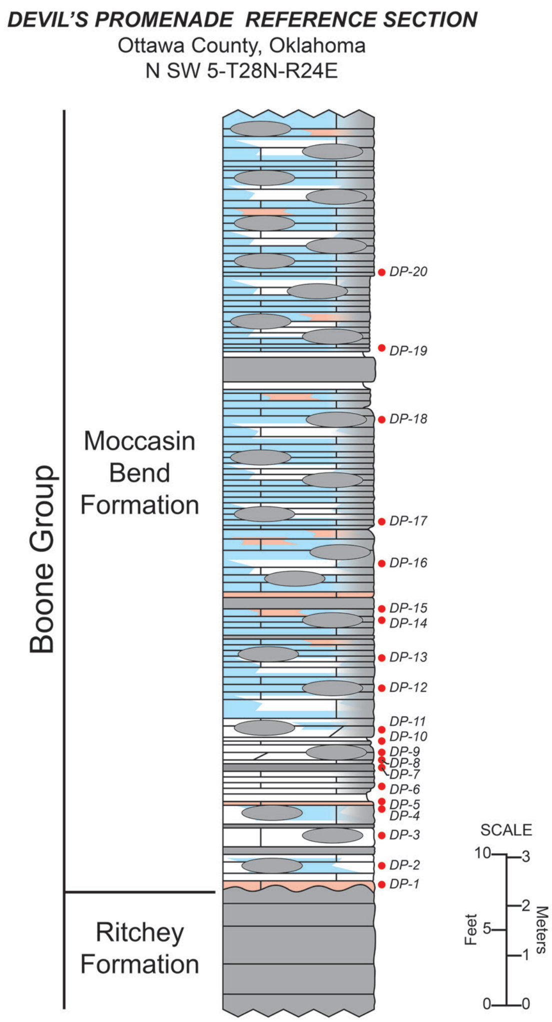


BURLINGTON SOUTH REFERENCE SECTION
Boone County, Arkansas
E NE 28-T20N-R21W



CEDAR CREEK REFERENCE SECTION
Newton County, Missouri
C SE 21-T26N-R32W

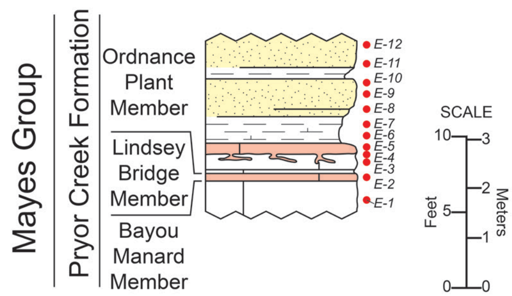


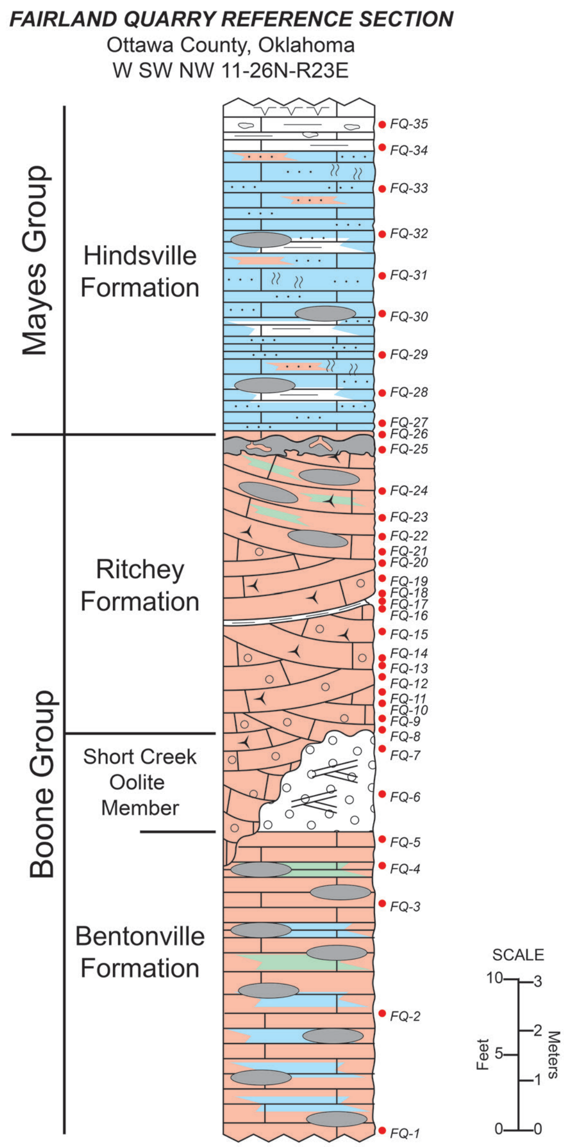

DEVIL'S PROMENADE REFERENCE SECTION
Ottawa County, Oklahoma
N SW 5-T28N-R24E
Boone Group
Moccasin Bend Formation
Ritchey Formation
DP-20
DP-19
DP-18
DP-17
DP-16
DP-15
DP-14
DP-13
DP-12
DP-11
DP-10
DP-9
DP-8
DP-7
DP-6
DP-5
DP-4
DP-3
DP-2
DP-1
SCALE
Feet
Meters
10
5
0
3
2
1
0

EARBOB REFERENCE SECTION

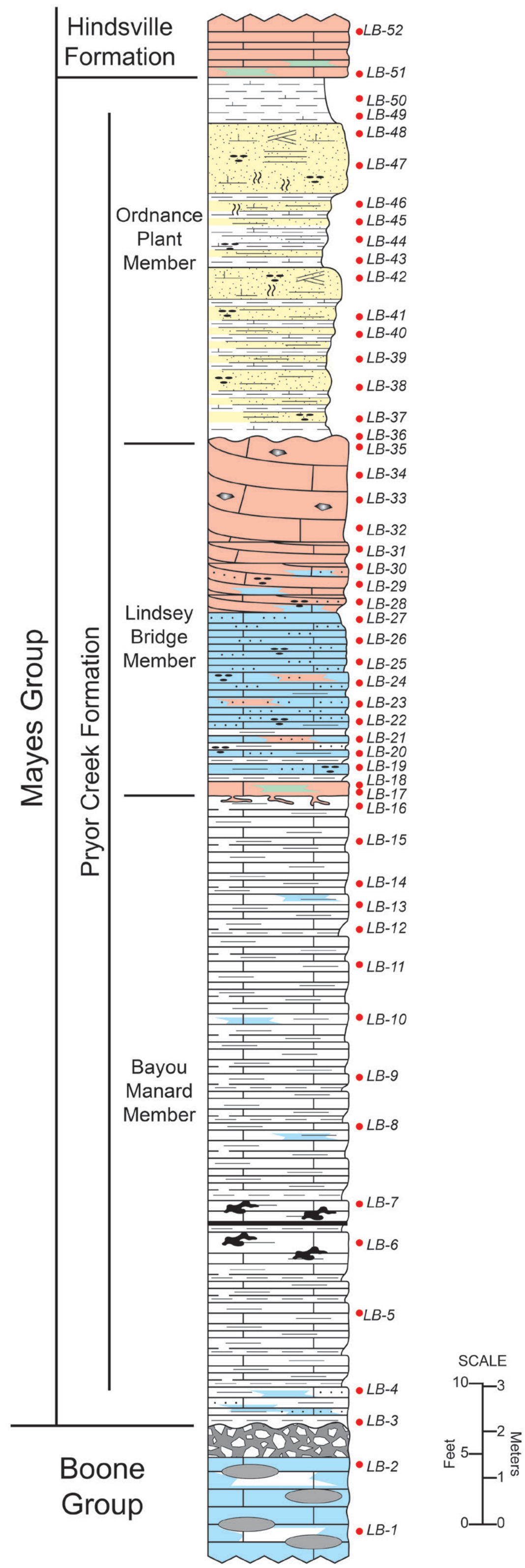
Mayes County, Oklahoma

E NW 31-T28N-R24E

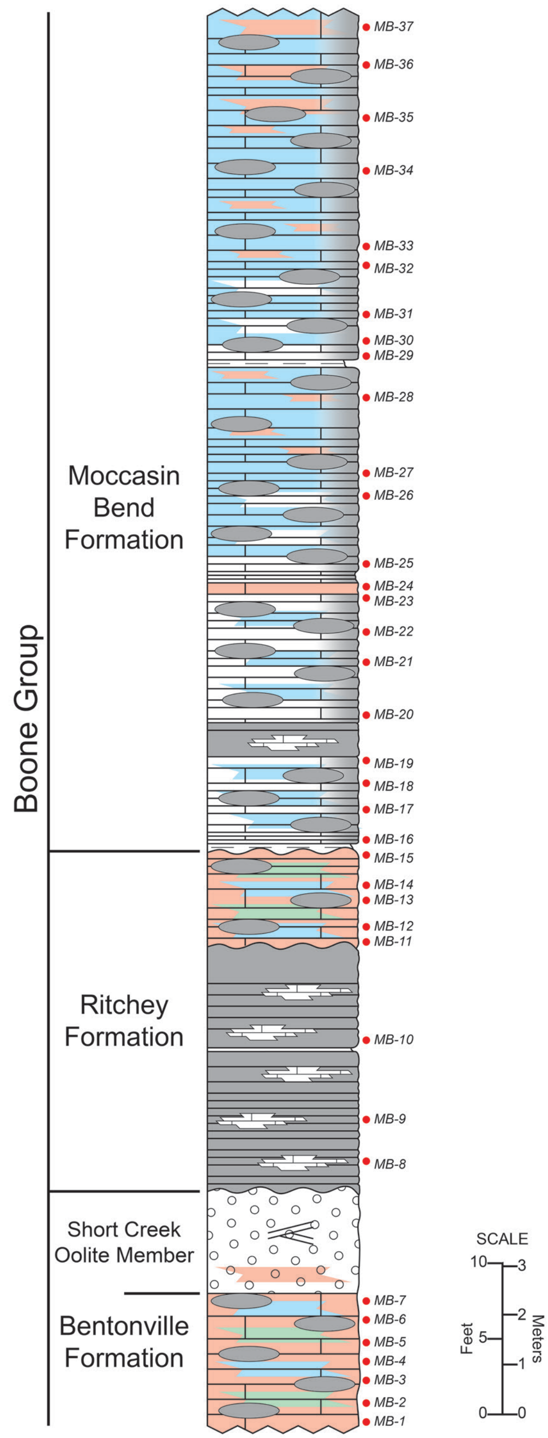



FAIRLAND QUARRY REFERENCE SECTION
Ottawa County, Oklahoma
W SW NW 11-26N-R23E
Mayes Group
Hindsville Formation
Boone Group
Ritchey Formation
Short Creek Oolite Member
Bentonville Formation
FQ-35
FQ-34
FQ-33
FQ-32
FQ-31
FQ-30
FQ-29
FQ-28
FQ-27
FQ-26
FQ-25
FQ-24
FQ-23
FQ-22
FQ-21
FQ-20
FQ-19
FQ-18
FQ-17
FQ-16
FQ-15
FQ-14
FQ-13
FQ-12
FQ-11
FQ-10
FQ-9
FQ-8
FQ-7
FQ-6
FQ-5
FQ-4
FQ-3
FQ-2
FQ-1
SCALE
Feet
Meters
10
5
0
3
2
1
0

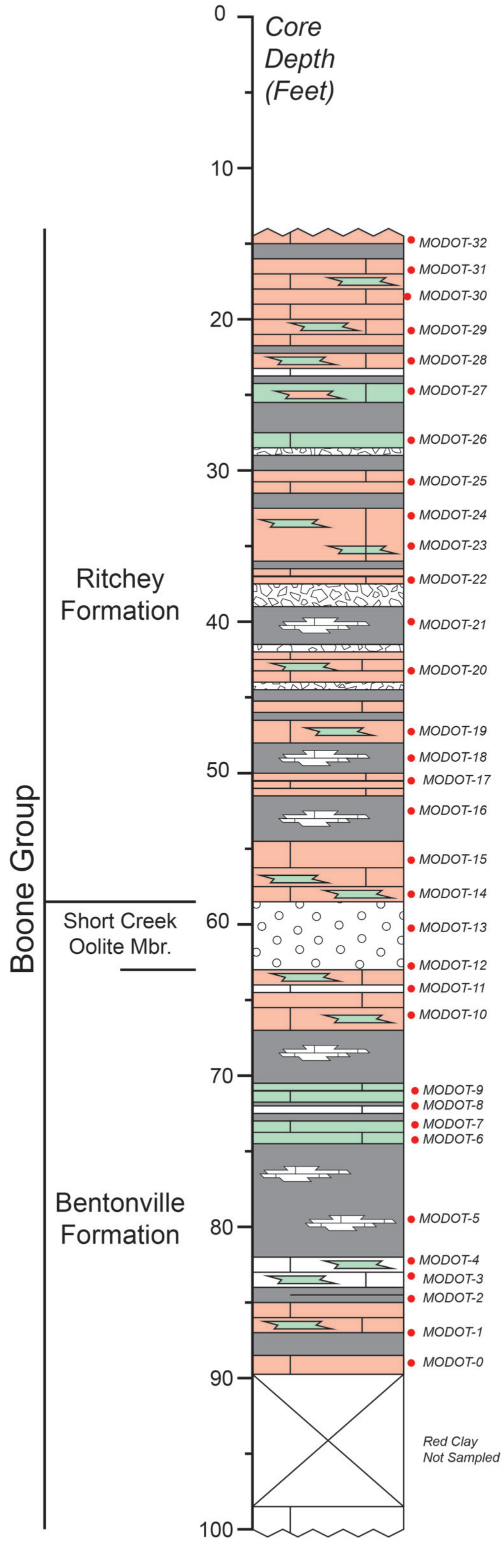
LINDSEY BRIDGE TYPE SECTION
Mayes County, Oklahoma
SW NW SW SEC 6-T20N-R20E



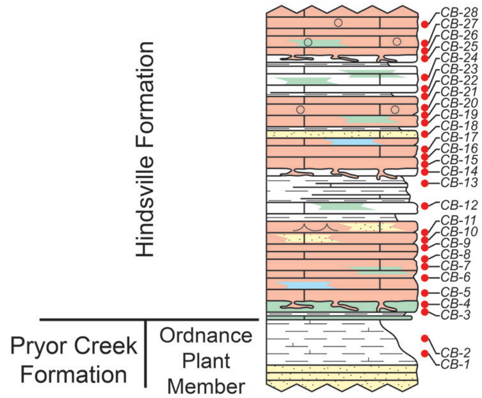
MOCCASIN BEND TYPE SECTION
Ottawa County, Oklahoma
S SW 30-T28N-R24E &
E NW 31-T28N-R24E



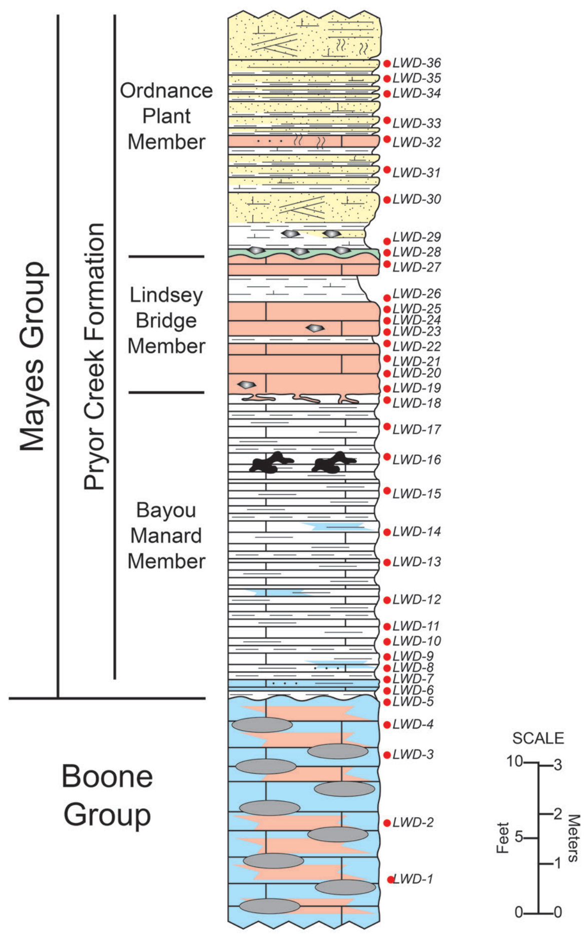
MISSOURI DEPARTMENT OF TRANSPORTATION (MODOT)
CORE B-49-8
Route 249 Drillcore
Jasper County, Missouri
NE SW NE 20-T28N-R32W



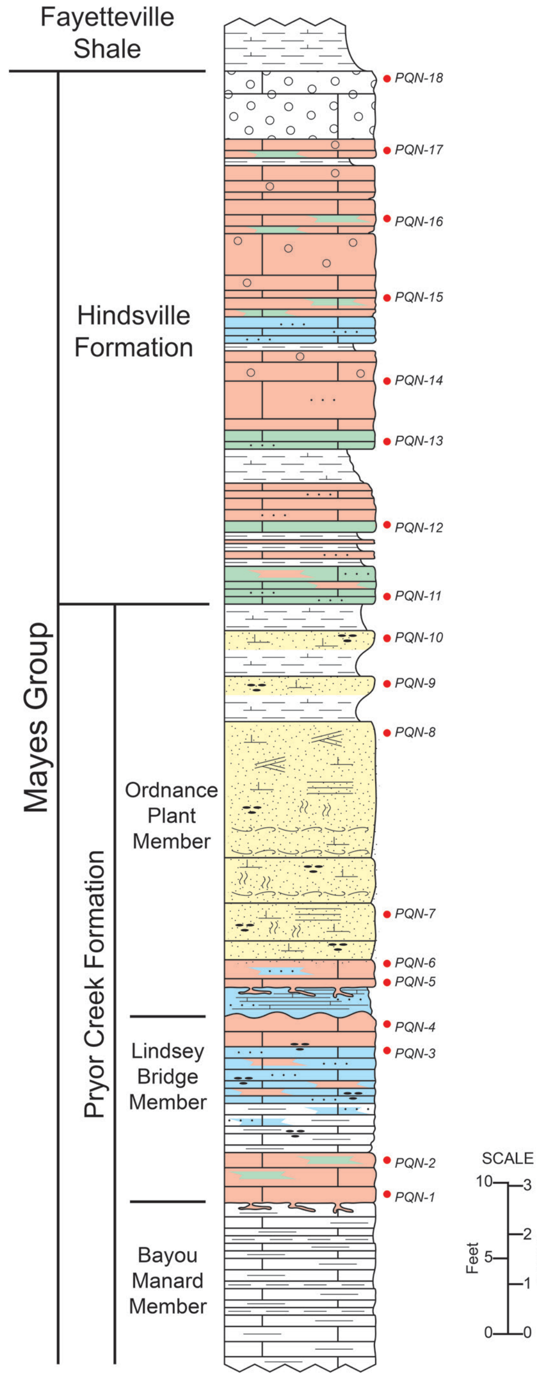
CHOUTEAU BEND REFERENCE LOCALITY
Mayes County, Oklahoma
SW SW SW 27-T20N-R19E



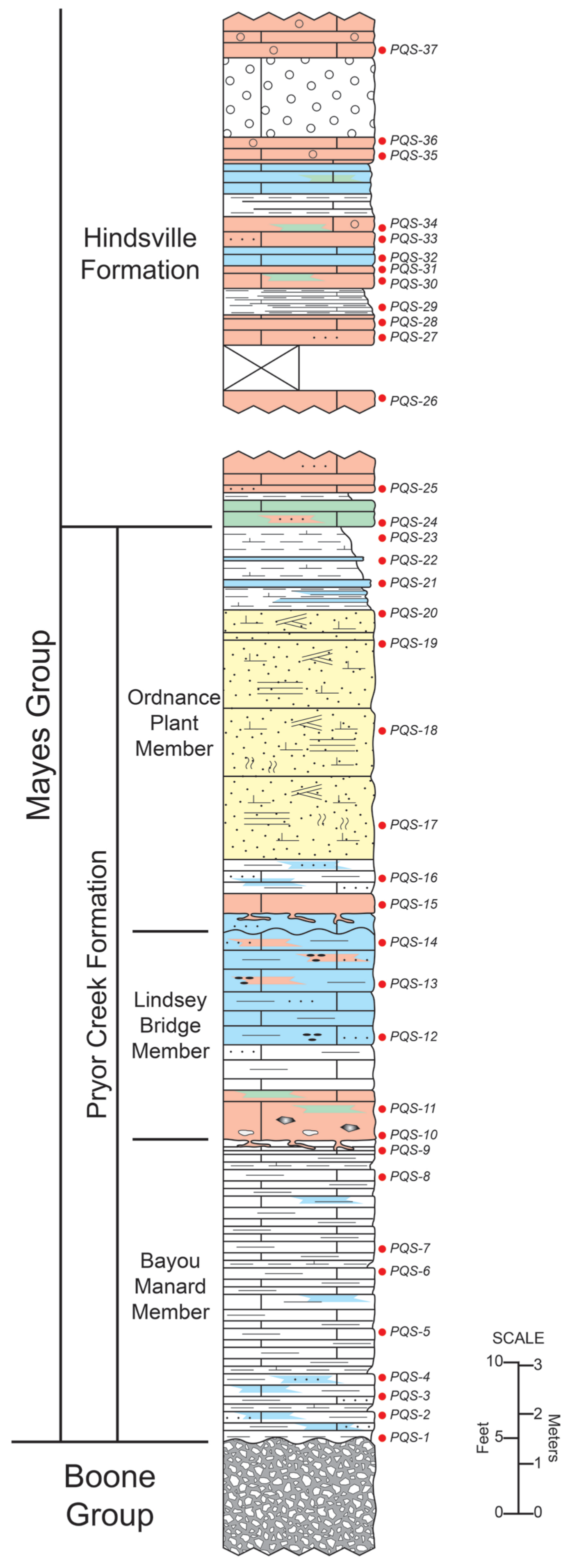
ORDNANCE PLANT TYPE SECTION
Mayes County, Oklahoma
SE SE 11 and NE 14-T20N-R19E

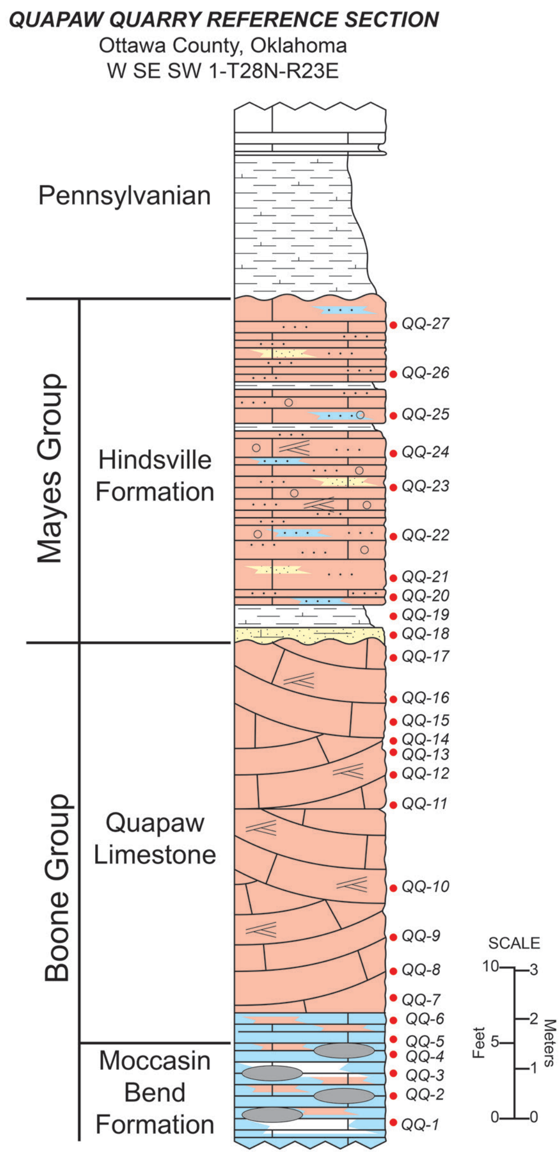


PRYOR CREEK TYPE LOCALITY
NORTH HIGH-WALL SECTION
PRYOR QUARRY
Mayes County, Oklahoma
NE SE 25-T21N-R19E

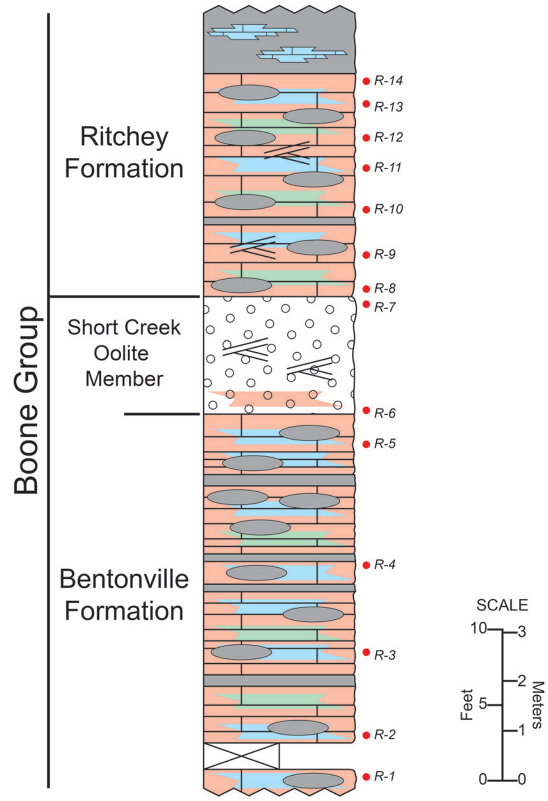


PRYOR QUARRY TYPE LOCALITY
SOUTH HIGH-WALL SECTION
PRYOR QUARRY
Mayes County, Oklahoma
SW NE 36-21N-19E




QUAPAW QUARRY REFERENCE SECTION
Ottawa County, Oklahoma
W SE SW 1-T28N-R23E
Pennsylvanian
Mayes Group
Hindsville Formation
Boone Group
Quapaw Limestone
Moccasin Bend Formation
QQ-27
QQ-26
QQ-25
QQ-24
QQ-23
QQ-22
QQ-21
QQ-20
QQ-19
QQ-18
QQ-17
QQ-16
QQ-15
QQ-14
QQ-13
QQ-12
QQ-11
QQ-10
QQ-9
QQ-8
QQ-7
QQ-6
QQ-5
QQ-4
QQ-3
QQ-2
QQ-1
SCALE
Feet
Meters
10
5
0
3
2
1
0

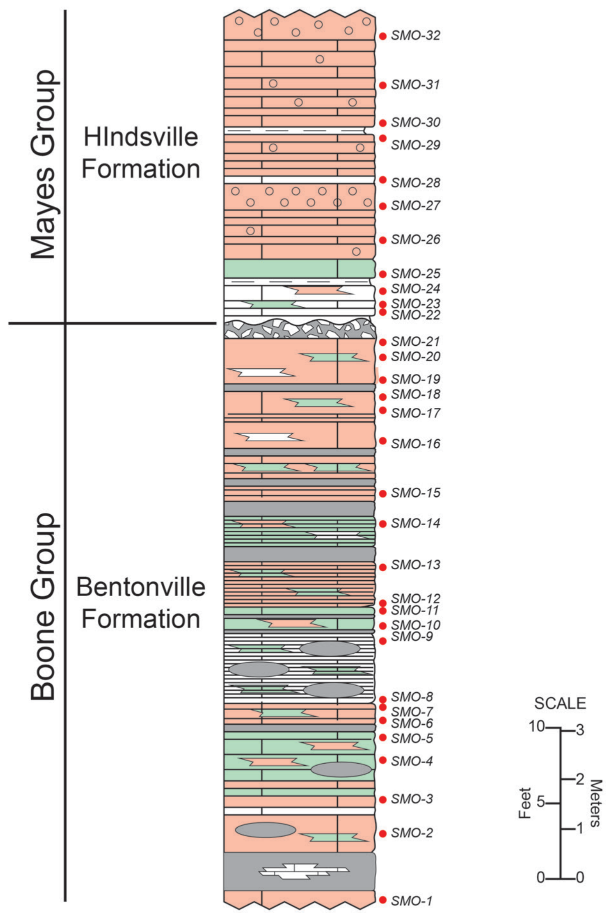
RITCHEY TYPE SECTION
Newton County, Missouri
U.S. Highway 60
N NW NW 1-T25N-R30W &
S SW SE 36-T26N-R30W



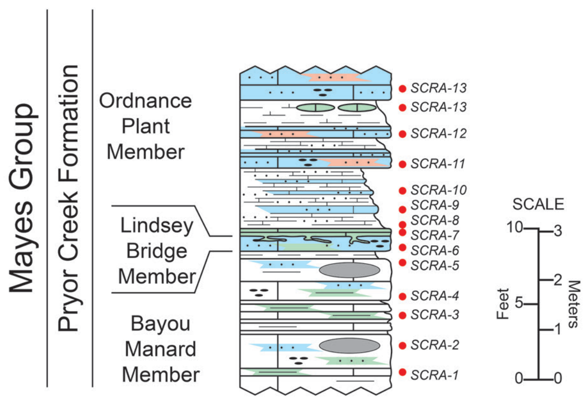
SELIGMAN REFERENCE SECTION

Barry Conty, Missouri

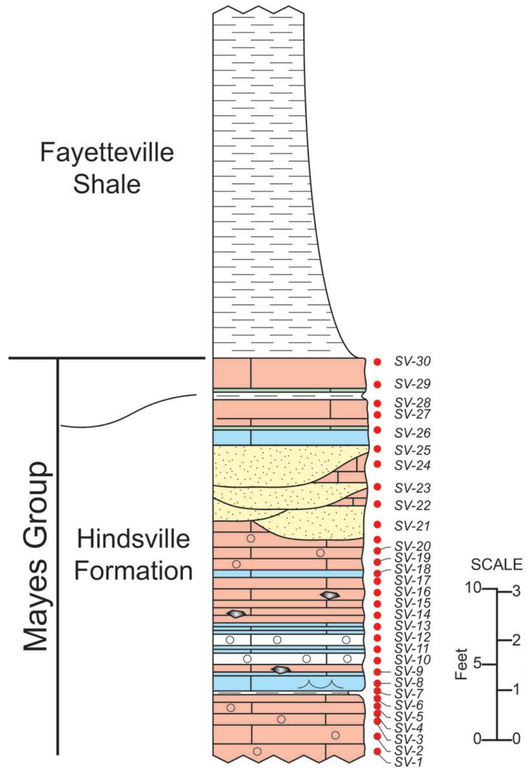
NE SW 4-T21N-R28W



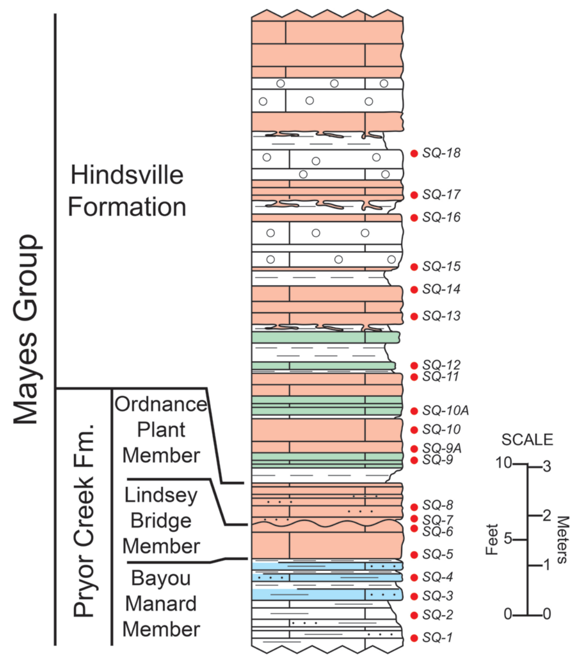
SPRING CREEK RECREATION AREA
MAYES COUNTY, OKLAHOMA
14 & 23-T19N-R19E

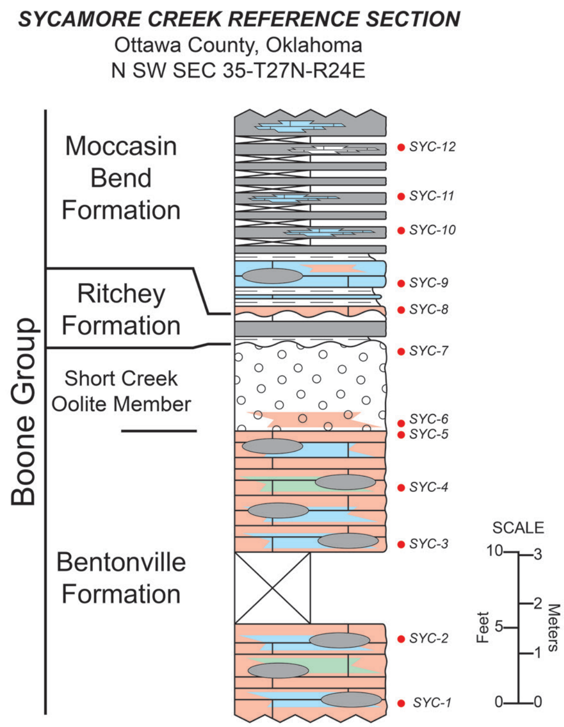


SPRING VALLEY REFERENCE SECTION
Washington County, Arkansas
SE NE NE 3-T17N-R28W



STILWELL QUARRY REFERENCE SECTION
Adair County, Oklahoma
NW NW SE 4-T14N-R25E




SYCAMORE CREEK REFERENCE SECTION
Ottawa County, Oklahoma
N SW SEC 35-T27N-R24E
Boone Group
Moccasin Bend Formation
Ritchey Formation
Short Creek Oolite Member
Bentonville Formation
SYC-12
SYC-11
SYC-10
SYC-9
SYC-8
SYC-7
SYC-6
SYC-5
SYC-4
SYC-3
SYC-2
SYC-1
SCALE
Feet
Meters
10
5
0
3
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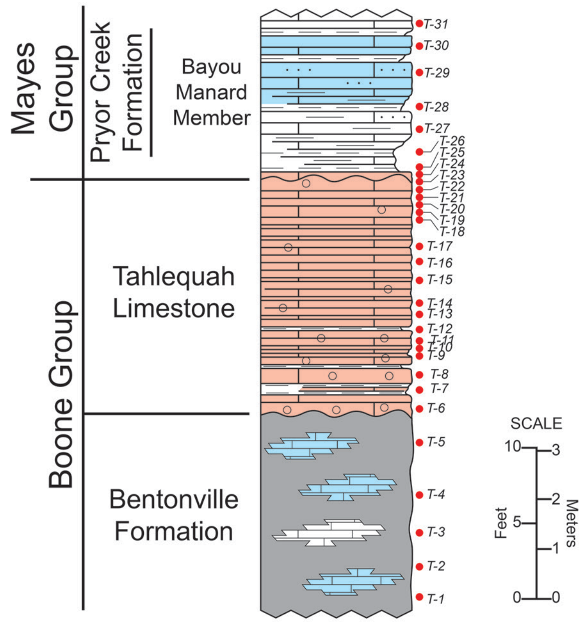
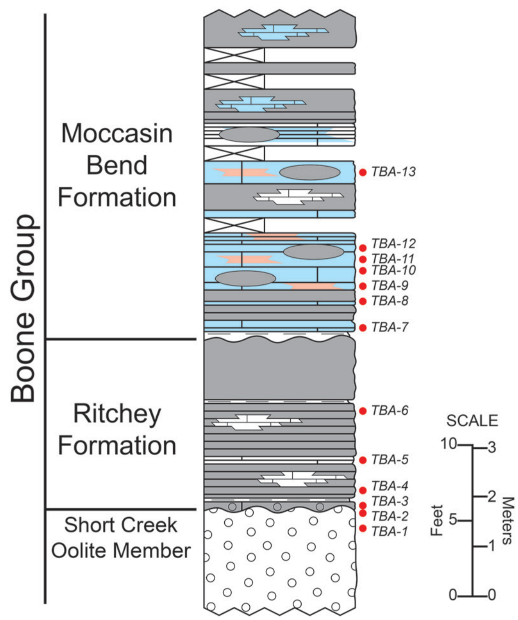
TAHLEQUAH PRINCIPAL REFERENCE SECTION
Cherokee County, Oklahoma
NW SE NE 4-T16N-R22E



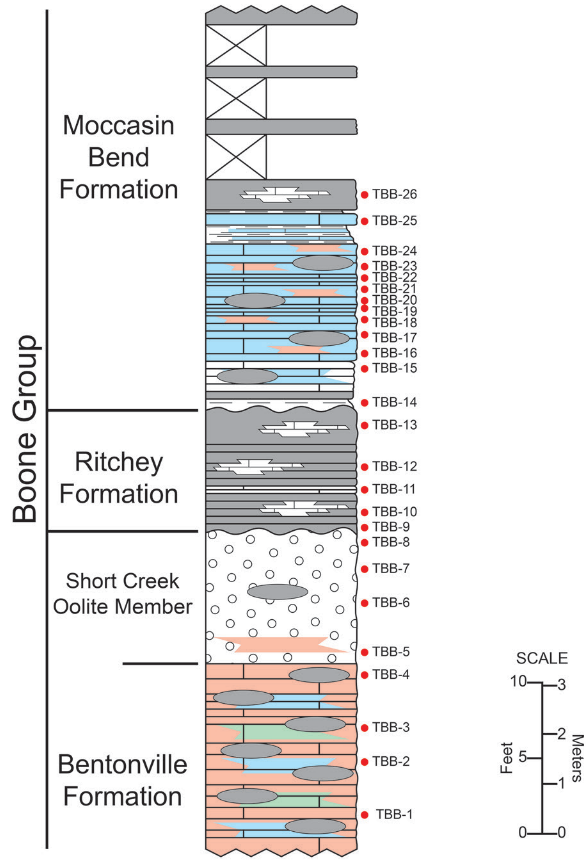
TWIN BRIDGES REFERENCE SECTION A
Ottawa County, Oklahoma
NE NE 29-T27N-R24E

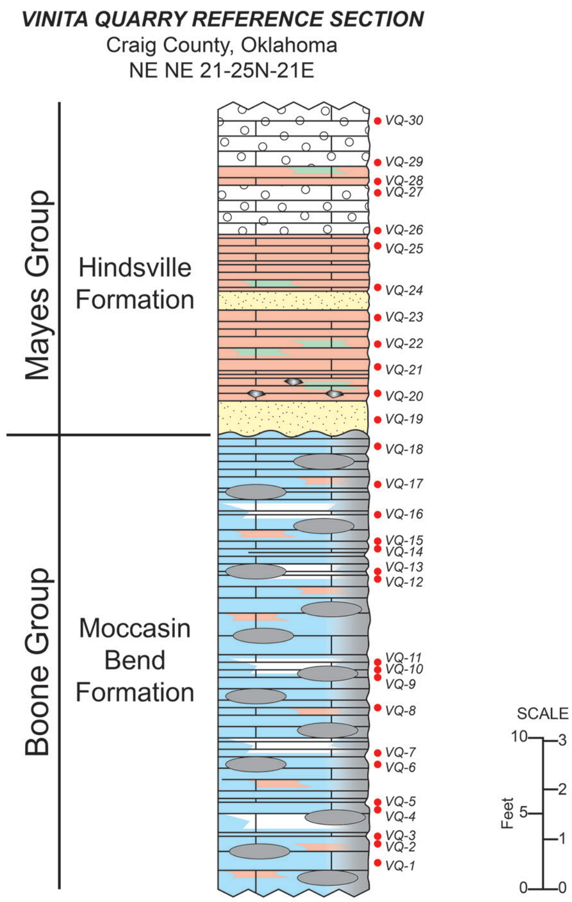


TWIN BRIDGES REFERENCE SECTION B

Ottawa County, Oklahoma

S SE 20-T27N-R24E




VINITA QUARRY REFERENCE SECTION
Craig County, Oklahoma
NE NE 21-25N-21E
Mayes Group
Hindsville Formation
Boone Group
Moccasin Bend Formation
VQ-30
VQ-29
VQ-28
VQ-27
VQ-26
VQ-25
VQ-24
VQ-23
VQ-22
VQ-21
VQ-20
VQ-19
VQ-18
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VQ-12
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VQ-4
VQ-3
VQ-2
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APPENDIX D: CONODONT PLATES

All specimens scaled to 60x; Scale bar in lower right hand corner is 500 microns.

All specimens held at the Paleontology Repository, Department of Earth and Environmental Sciences, University of Iowa.

PLATE 1 - *Cavusgnathus*

Figure A – *Cavusgnathus charactus* (Rexroad); Quapaw Limestone Boone Group, Quapaw Quarry Reference Locality, Sample QQ-5, SUI 141173.

Figure B – *Cavusgnathus unicornis* (Youngquist and Miller); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Earbob Recreation Area Reference Locality, Sample E-6, SUI 141275.

Figure C – *Cavusgnathus regularis* (Youngquist and Miller); Hindsville Formation, Mayes Group, Chouteau Bend Reference Locality, Sample CB-9, SUI 141283.

Figure D – *Cavusgnathus altus* (Harris and Hollingsworth); Hindsville Formation, Mayes Group, Chouteau Bend Reference Locality, Sample CB-4, SUI 141286

Figure E – *Cavusgnathus convexa* (Rexroad); Hindsville Formation, Mayes Group, Chouteau Bend Reference Locality, Sample CB-7, SUI 141303.

Figure F – *Cavusgnathus regularis* (Youngquist and Miller); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141365.

Figure G – *Cavusgnathus altus* (Harris and Hollingsworth); Moccasin Bend Formation, Boone Group, Vinita Quarry Reference Locality, Sample VQ-2, SUI 141219.

Figure H – *Cavusgnathus charactus* (Rexroad); Moccasin Bend Formation, Boone Group, Moccasin Bend Type Locality, Sample MB-30, SUI 141230.

Figures I – Cavusgnathus altus (Harris and Hollingsworth); Moccasin Bend Formation, Boone Group, Moccasin Bend Type Locality, Sample MB-24, SUI 141702.

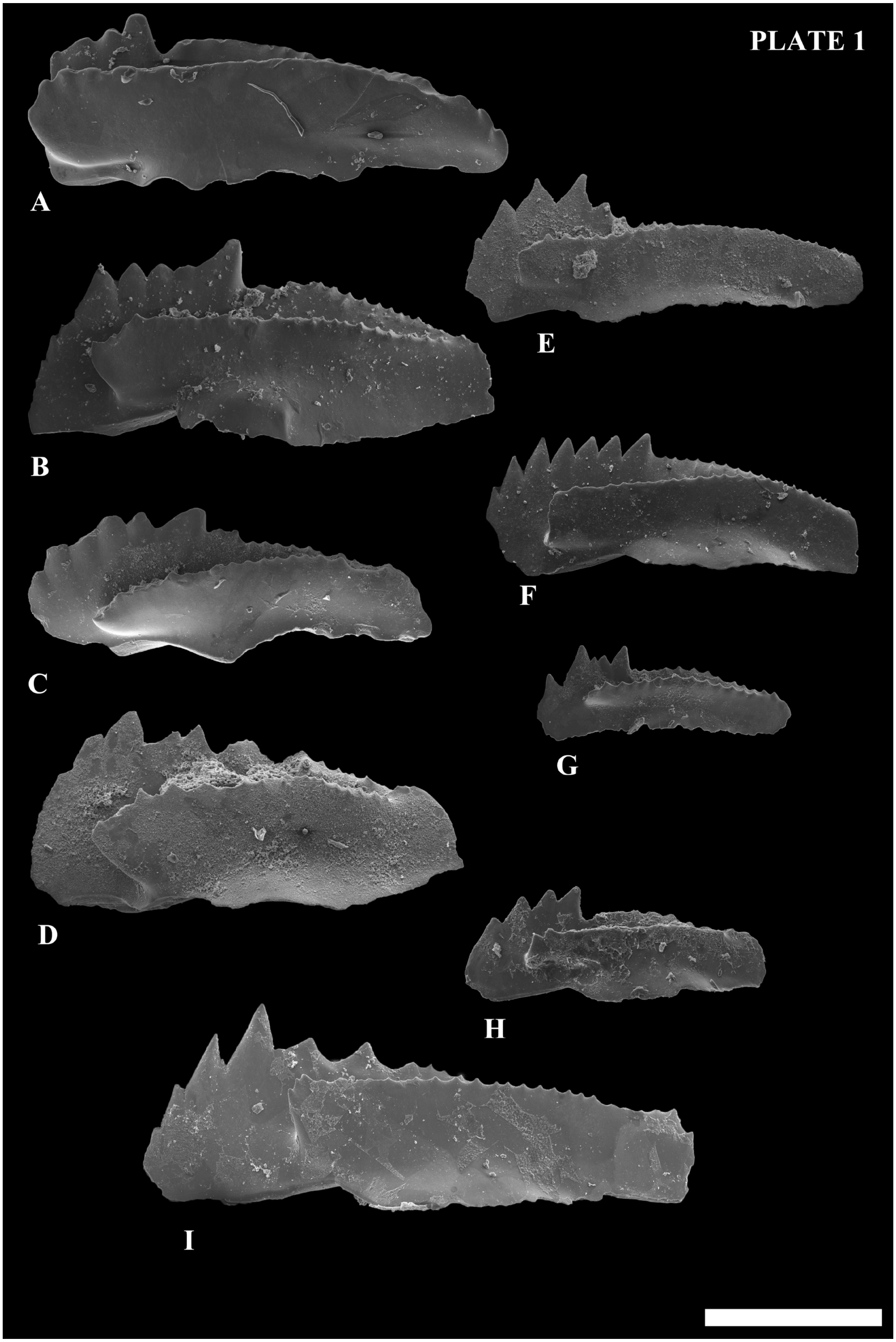
PLATE 1
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PLATE 2 – *Gnathodus bilineatus* (Roundy)

Figure A – *Gnathodus bilineatus* (Roundy); Hindsville Formation, Mayes Group, Chouteau Bend Reference Locality, Sample CB-4, SUI 141284.

Figure B – *Gnathodus bilineatus* (Roundy); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-4, SUI 141311.

Figure C – *Gnathodus bilineatus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141367.

Figure D – *Gnathodus bilineatus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141366.

Figure E – *Gnathodus bilineatus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141640.

Figure F – *Gnathodus bilineatus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141348.

Figure G – *Gnathodus bilineatus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141331.

Figure H – *Gnathodus bilineatus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Earbob Recreation Area Reference Locality, Sample E-6, SUI 141264.

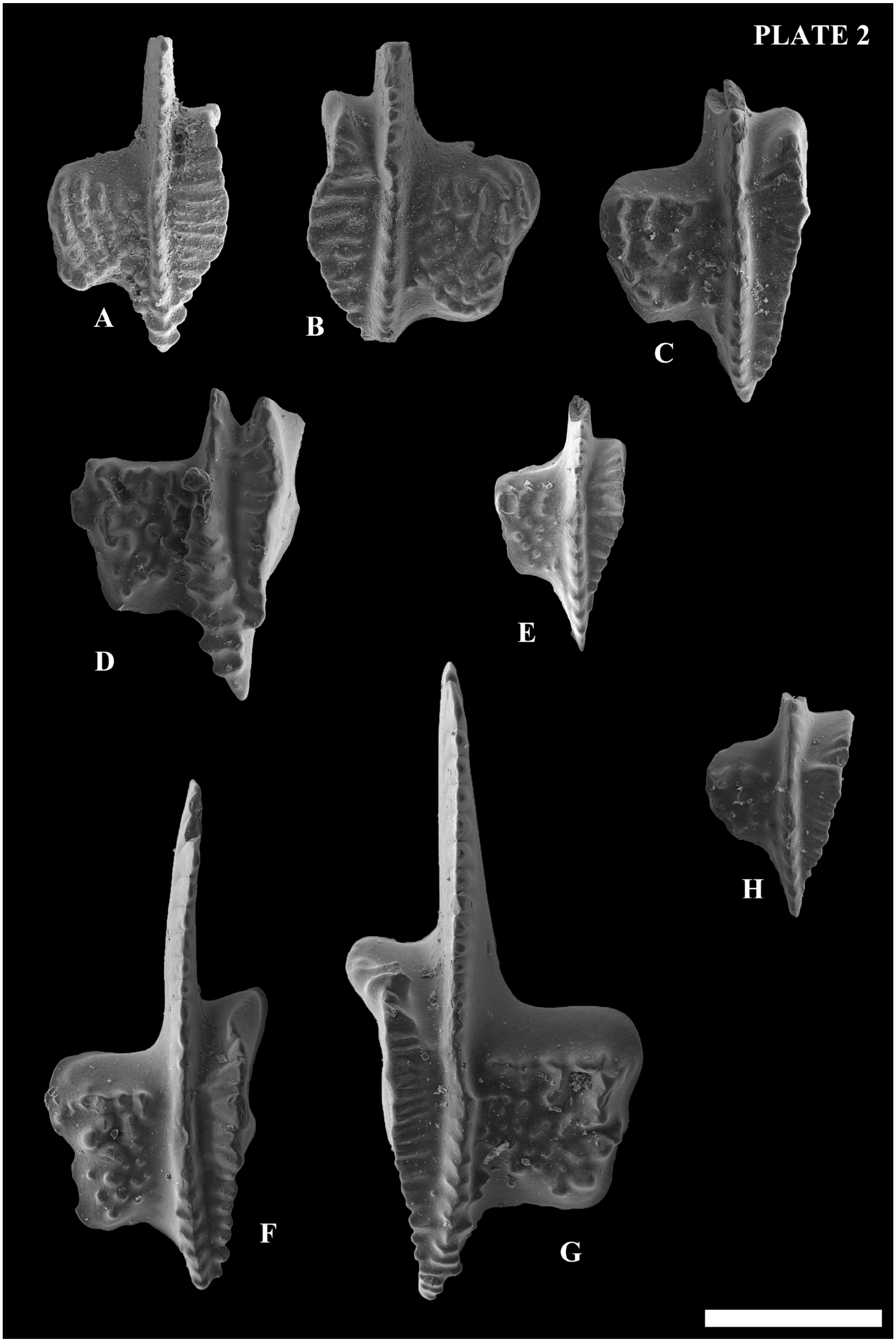
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PLATE 3 – *Gnathodus girtyi girtyi* (Hass)

Figure A – *Gnathodus girtyi girtyi* (Hass); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam) Sample LWD-25, SUI 141260.

Figure B – *Gnathodus girtyi girtyi* (Hass); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141201.

Figure C – *Gnathodus girtyi girtyi* (Hass); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141332.

Figure D – *Gnathodus girtyi girtyi* (Hass); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141334.

Figure E – *Gnathodus girtyi girtyi* (Hass); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141350.

Figure F – *Gnathodus girtyi girtyi* (Hass); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Earbob Recreation Area Reference Locality, Sample E-7, SUI 141249.

Figure G – *Gnathodus girtyi girtyi* (Hass); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-19, SUI 141621.

Figure H – *Gnathodus girtyi girtyi* (Hass); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141255.

Figure I – *Gnathodus girtyi girtyi* (Hass); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141374.

Figure J – *Gnathodus girtyi girtyi* (Hass); _ Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141200.

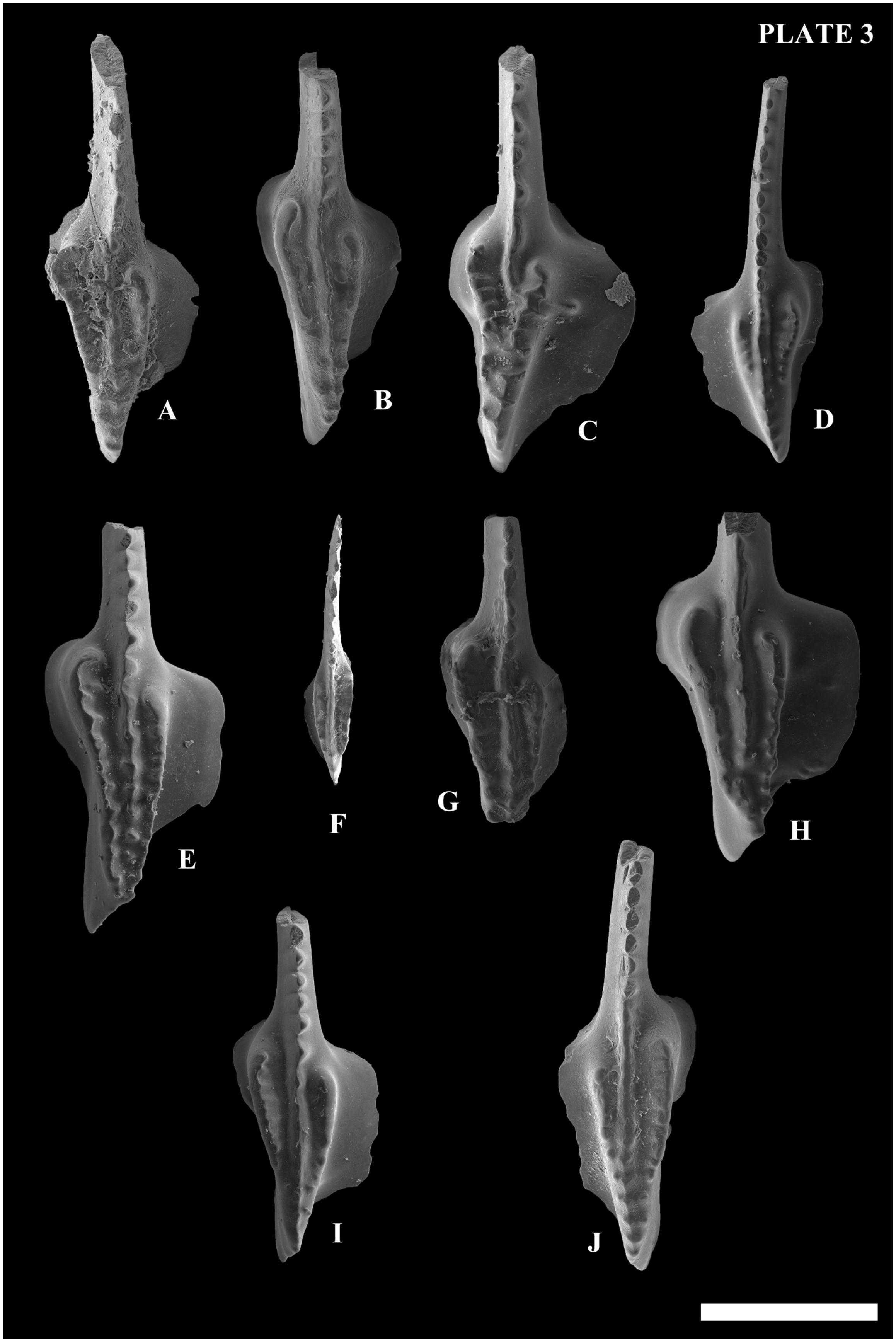
PLATE 3
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PLATE 4 – *Gnathodus linguiformis* (Branson and Mehl) and *Gnathodus pseudosemiglaber* (Thompson and Fellows)

Figure A – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Bentonville Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-2

Figure B – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Bentonville Formation, Boone Group, Seligman Reference Locality, Sample SMO-10

Figure C – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-8, SUI 141191.

Figure D – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-9, SUI 141670.

Figure E – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-9, SUI 141674.

Figure F – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-8, SUI 141662.

Figure G – *Gnathodus pseudosemiglaber* (Thompson and Fellows); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-15, SUI 141570.

Figure H – *Gnathodus linguiformis* (Branson and Mehl); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141188.

Figure I – *Gnathodus linguiformis* (Branson and Mehl); Ritchey Formation, Boone Group, Ritchey Type Locality, Sample R-9.

Figure J – *Gnathodus linguiformis* (Branson and Mehl); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-8, SUI 141665.

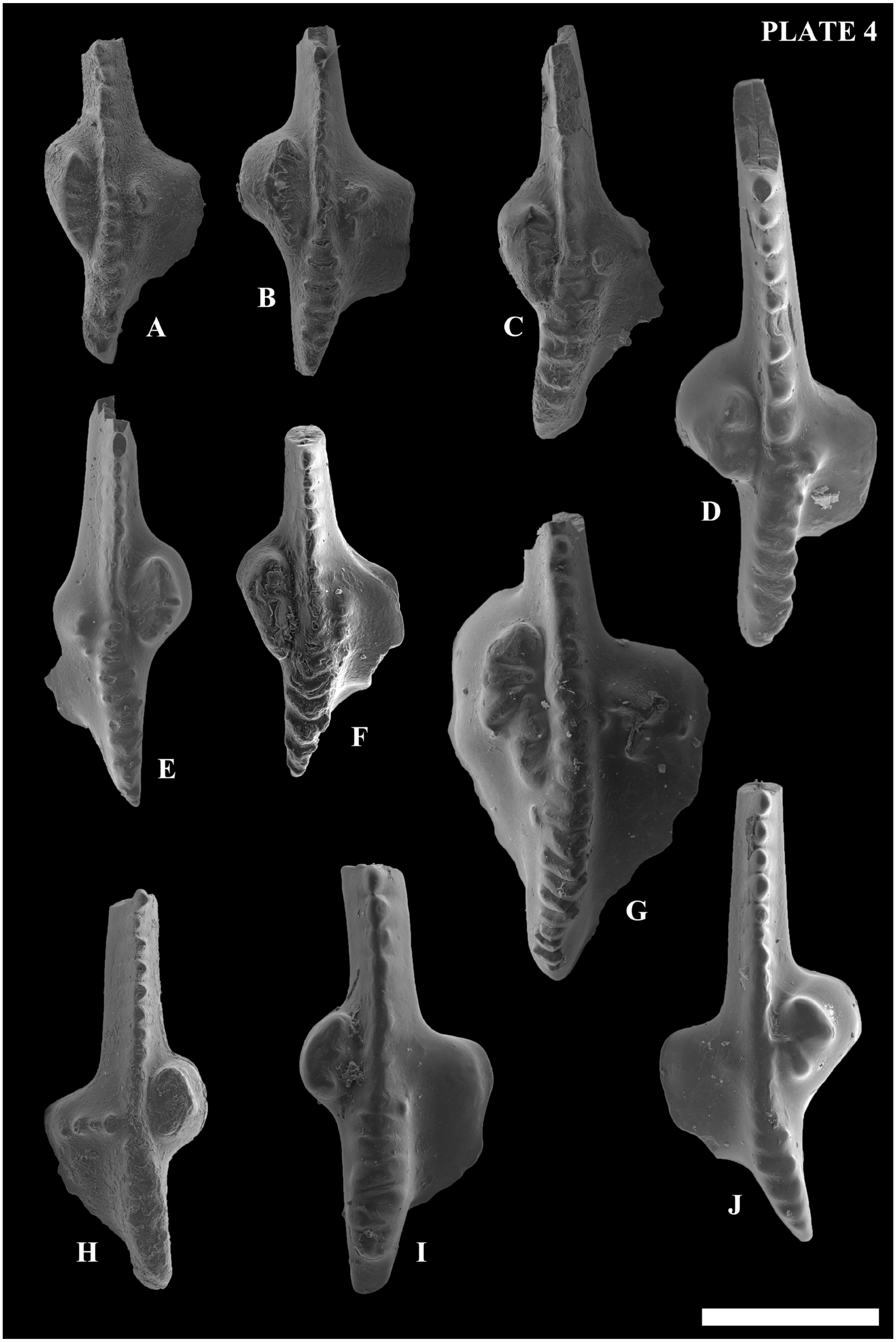
PLATE 4
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PLATE 5 – *Gnathodus texanus* (Roundy)

Figure A – *Gnathodus texanus* (Roundy); Bayou Manard Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-7, SUI 141431.

Figure B – *Gnathodus texanus* (Roundy); Bayou Manard Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-7, SUI 141432.

Figure C – *Gnathodus texanus* (Roundy); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-4, SUI 141310.

Figure D – *Gnathodus texanus* (Roundy); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-4, SUI 141312.

Figure E – *Gnathodus texanus* (Roundy); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-3, SUI 141321.

Figure F – *Gnathodus texanus* (Roundy); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Lindsey Bridge Type Locality, Sample LB-34, SUI 141251.

Figure G – *Gnathodus texanus* (Roundy); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-22, SUI 141622.

Figure H – *Gnathodus texanus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Earbob Recreation Area Reference Locality, Sample E-6, SUI 141269.

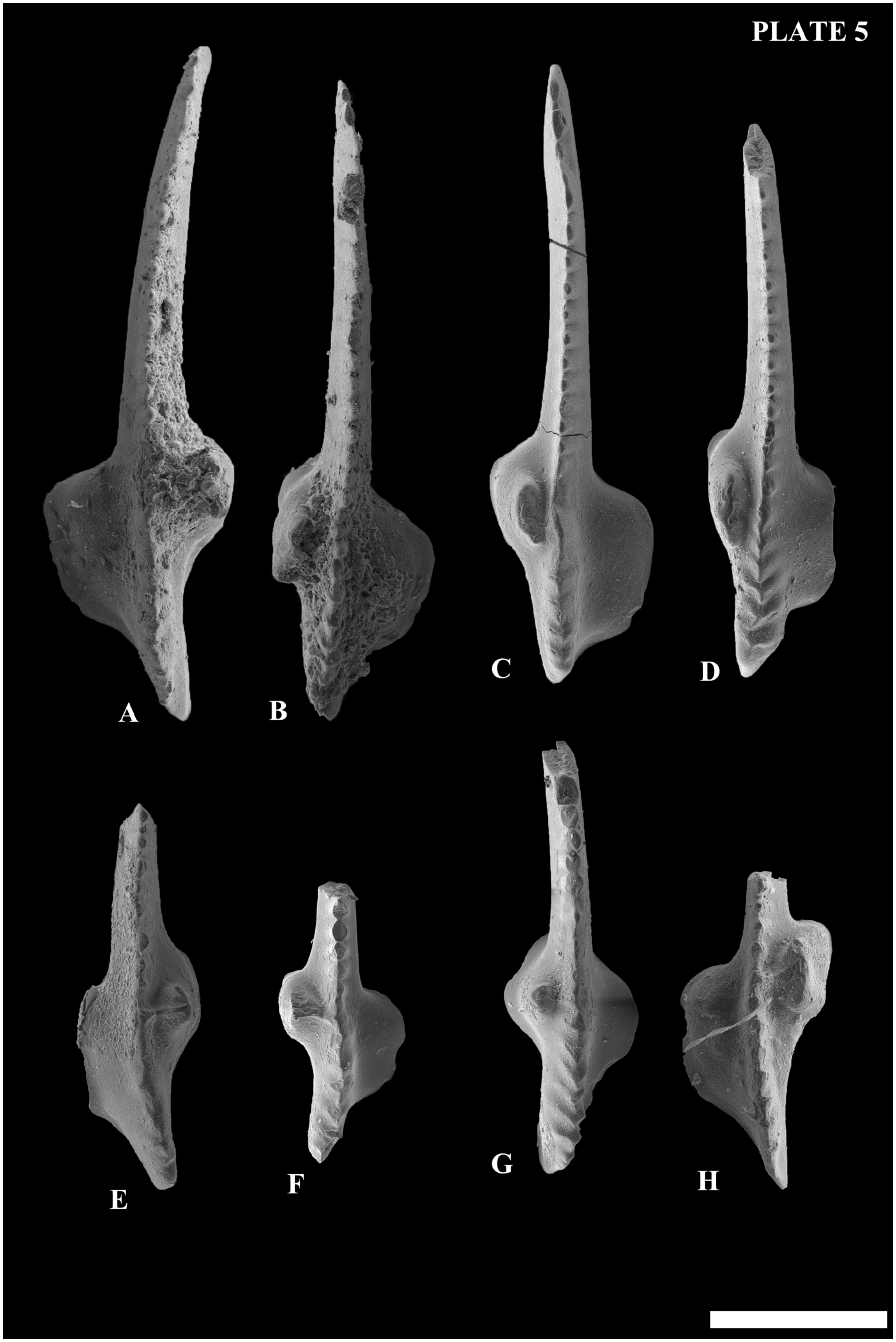
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PLATE 6 – *Gnathodus texanus* (Roundy)

Figure A – *Gnathodus texanus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141351.

Figure B – *Gnathodus texanus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141353.

Figure C – *Gnathodus texanus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141358.

Figure D – *Gnathodus texanus* (Roundy); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141632.

Figure E – *Gnathodus texanus* (Roundy); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141554.

Figure F – *Gnathodus texanus* (Roundy); Moccasin Bend Formation, Mayes Group, Devil's Promenade Reference Locality, Sample DP-14, SUI 141243.

Figure G – *Gnathodus texanus* (Roundy); Quapaw Limestone, Boone Group, Quapaw Quarry Reference Locality, Sample QQ-5, SUI 141450

Figure H – *Gnathodus texanus* (Roundy); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-8, SUI 141192.

Figure I – *Gnathodus texanus* (Roundy); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-13, SUI 141574.

Figure J – *Gnathodus texanus* (Roundy); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-14, SUI 141582.

Figure K – *Gnathodus texanus* (Roundy); Moccasin Bend Formation, Boone Group, Vinita Quarry Reference Locality, Sample VQ-2, SUI 141469.

Figure L – *Gnathodus texanus* (Roundy); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-9, SUI 141672.

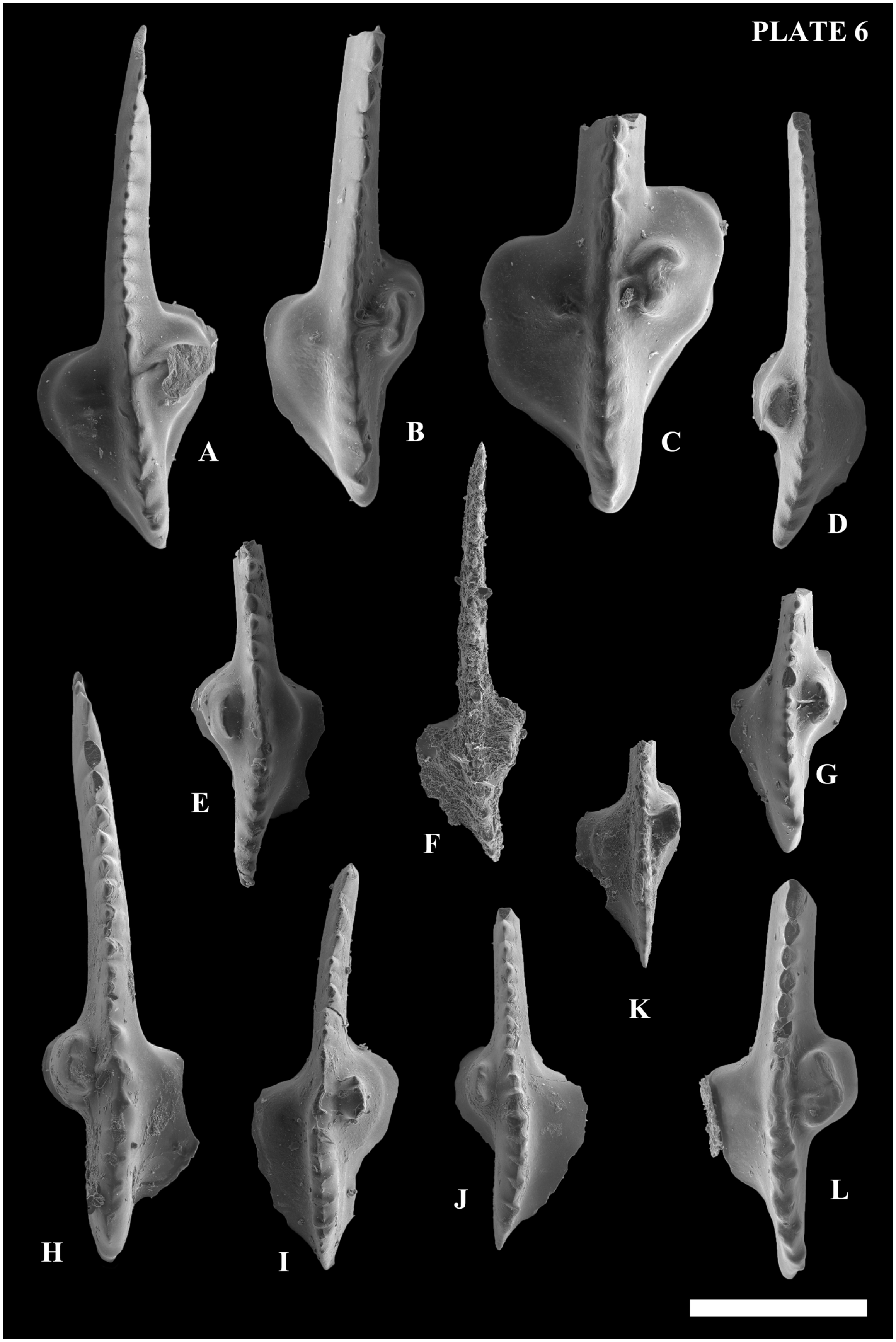
PLATE 6
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PLATE 7 – *Gnathodus* n. sp. 15 (aff. *punctatus)* Boardman et al. (2013)

Figure A – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-15, SUI 141683.

Figure B – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-10, SUI 141679.

Figure C – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Ritchey Formation, Boone Group, Cedar Creek Reference Locality, Sample CC-7.

Figure D – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-15, SUI 141196.

Figure E – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141177.

Figure F – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-16, SUI 141685.

Figure G – *Gnathodus* n. sp. 15 (aff. punctatus) Boardman et al. (2013); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-18, SUI 141643.

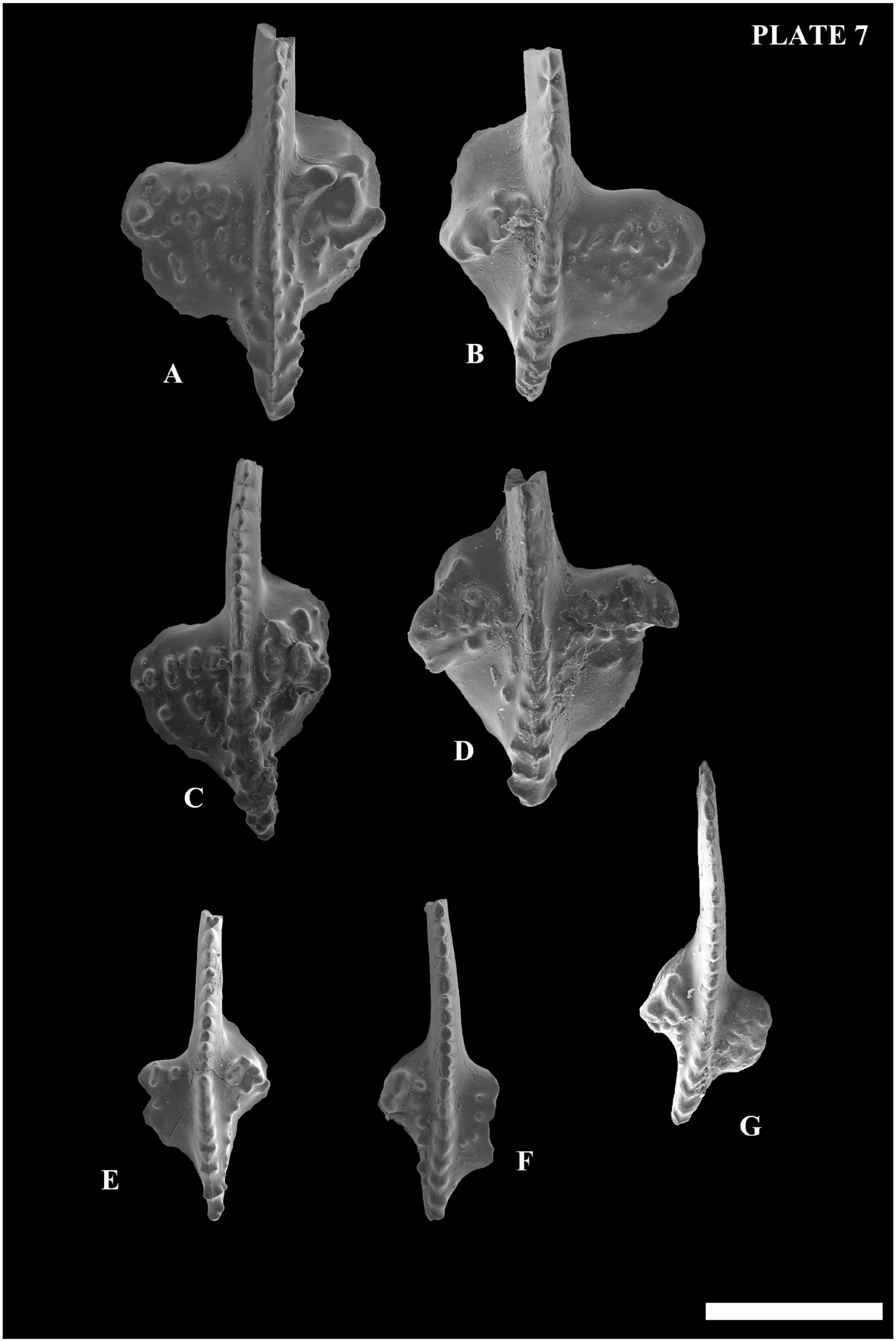
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PLATE 8 – *Gnathodus* sp. A

Figure A – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-15, SUI 141566.

Figure B – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-20, SUI 141545.

Figure C – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141174.

Figure D – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-12, SUI 141577.

Figure E – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-14, SUI 141583.

Figure F – *Gnathodus* sp. A; Mixing Zone, Boone Group, Tahlequah Principal Reference Locality, Sample T-23, SUI 141512.

Figure G – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141606.

Figure H – *Gnathodus* sp. A; Mixing Zone, Boone Group, Tahlequah Principal Reference Locality, Sample T-23, SUI 141523.

Figure I – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-13, SUI 141644.

Figure J – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-14, SUI 141580.

Figure K – *Gnathodus* sp. A; Mixing Zone, Tahlequah Principal Reference Locality, Sample T-23, SUI 141510.

Figure L – *Gnathodus* sp. A; Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141553.

Figure M – *Gnathodus* sp. A; Mixing Zone, Tahlequah Principal Reference Locality, Sample T-23, SUI 141507.

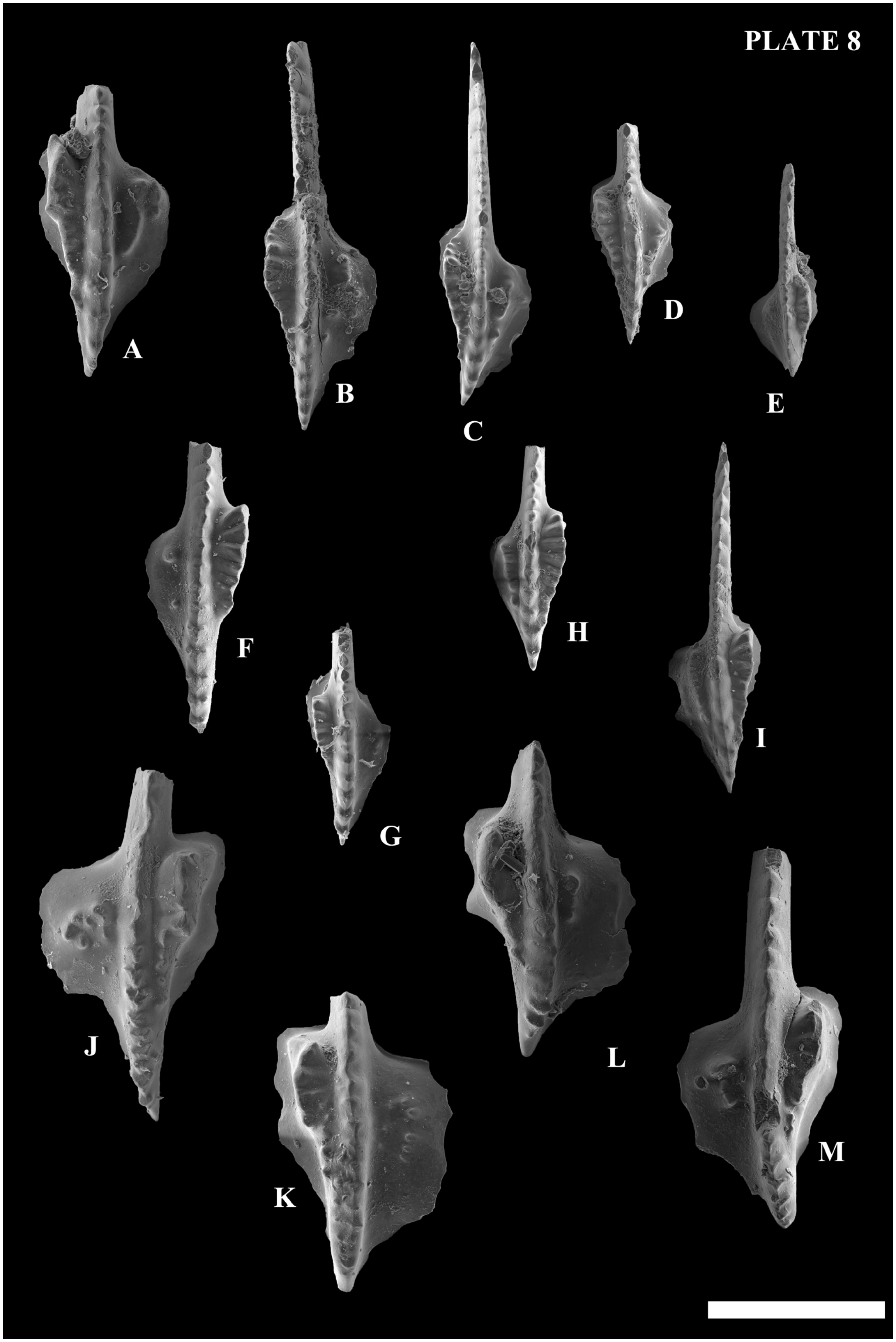
PLATE 8
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PLATE 9 – *Hindeodus cristula* and *Hindeodontoides spicules*

Figure A – *Hindeodus cristula* (Youngquist and Miller, 1949); Moccasin Bend Formation, Boone Group, Vinita Quarry Reference Locality, Sample VQ-2, SUI 141458.

Figure B – *Hindeodus cristula* (Youngquist and Miller, 1949); Moccasin Bend Formation, Boone Group, Vinita Quarry Reference Locality, Sample VQ-2, SUI 141217.

Figure C – *Hindeodus cristula* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141631.

Figure D – *Hindeodus cristula* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141639.

Figure E – *Hindeodontoides spiculus* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141627.

Figure F – *Hindeodontoides spiculus* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141635.

Figure G – *Hindeodontoides spiculus* (Youngquist and Miller, 1949); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141633.

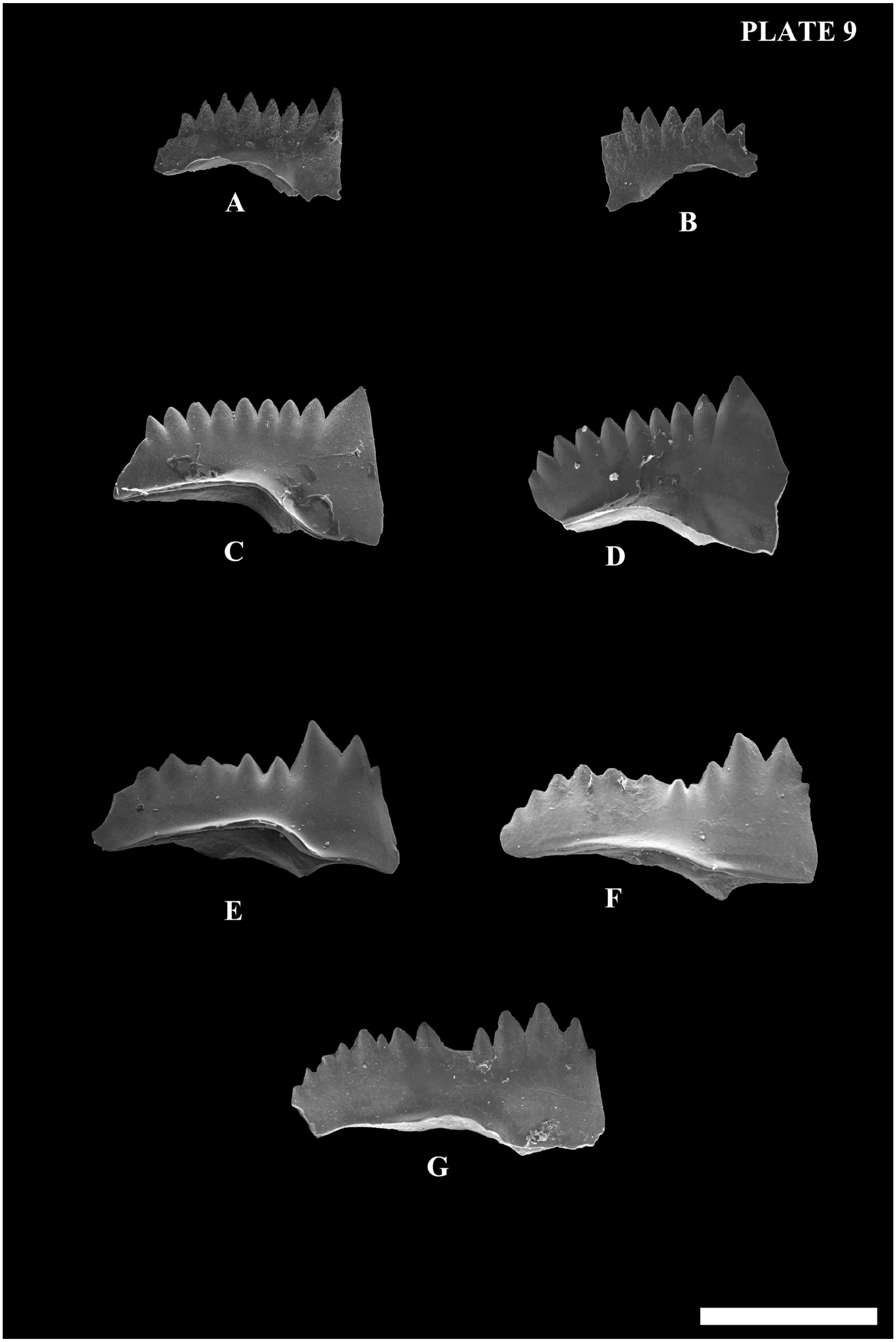
PLATE 9
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PLATE 10 - *Lochriea*

Figure A – *Lochriea homopunctatus* (Ziegler); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141185.

Figure B – *Lochriea homopunctatus* (Ziegler); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141206.

Figure C – *Lochriea homopunctatus* (Ziegler); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Lindsey Bridge Type Locality, Sample LB-22, SUI 141254.

Figure D – *Lochriea homopunctatus* (Ziegler); Moccasin Bend Formation, Boone Group, Vinita Quarry Reference Locality, Sample VQ-2, SUI 141453.

Figure E – *Lochriea homopunctatus* (Ziegler); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-19, SUI 141605.

Figure F – *Lochriea homopunctatus* (Ziegler); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Stilwell Quarry Reference Locality, Sample SQ-6, SUI 141492.

Figure G – *Lochriea homopunctatus* (Ziegler); Bayou Manard Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-7, SUI 141615.

Figure H – *Lochriea homopunctatus* (Ziegler); Tahlequah Limestone, Boone Group, Tahlequah Principal Reference Locality, Sample T-21, SUI 141560.

Figure I – *Lochriea homopunctatus* (Ziegler); Moccasin Bend Formation, Boone Group, Vinita Quarry Reference Locality, Sample VQ-2, SUI 141456.

Figure J – *Lochriea* sp.; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141636.

Figure K – *Lochriea* sp.; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141377.

Figure L – *Lochriea commutata* (Branson and Mehl); Hindsville Formation, Mayes Group, Chouteau Bend Reference Locality, Sample CB-4, SUI 141288.

Figure M – *Lochriea commutata* (Branson and Mehl); Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Lindsey Bridge Type Locality, Sample LB-26, SUI 141252.

Figure N – *Lochriea commutata* (Branson and Mehl); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-13, SUI 141325.

Figure O – *Lochriea commutata* (Branson and Mehl); Hindsville Formation, Mayes Group, Chouteau Bend Reference Locality, Sample CB-9, SUI 141278.

Figure P – *Lochriea commutata* (Branson and Mehl); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-25, SUI 1413319.

Figure Q – *Lochriea commutata* (Branson and Mehl); Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Bidding Creek Reference Locality, Sample BC-5, SUI 141590.

Figure R – *Lochriea commutata* (Branson and Mehl); Hindsville Formation, Mayes Group, Spring Valley Reference Locality, Sample SV-25, SUI 141317.

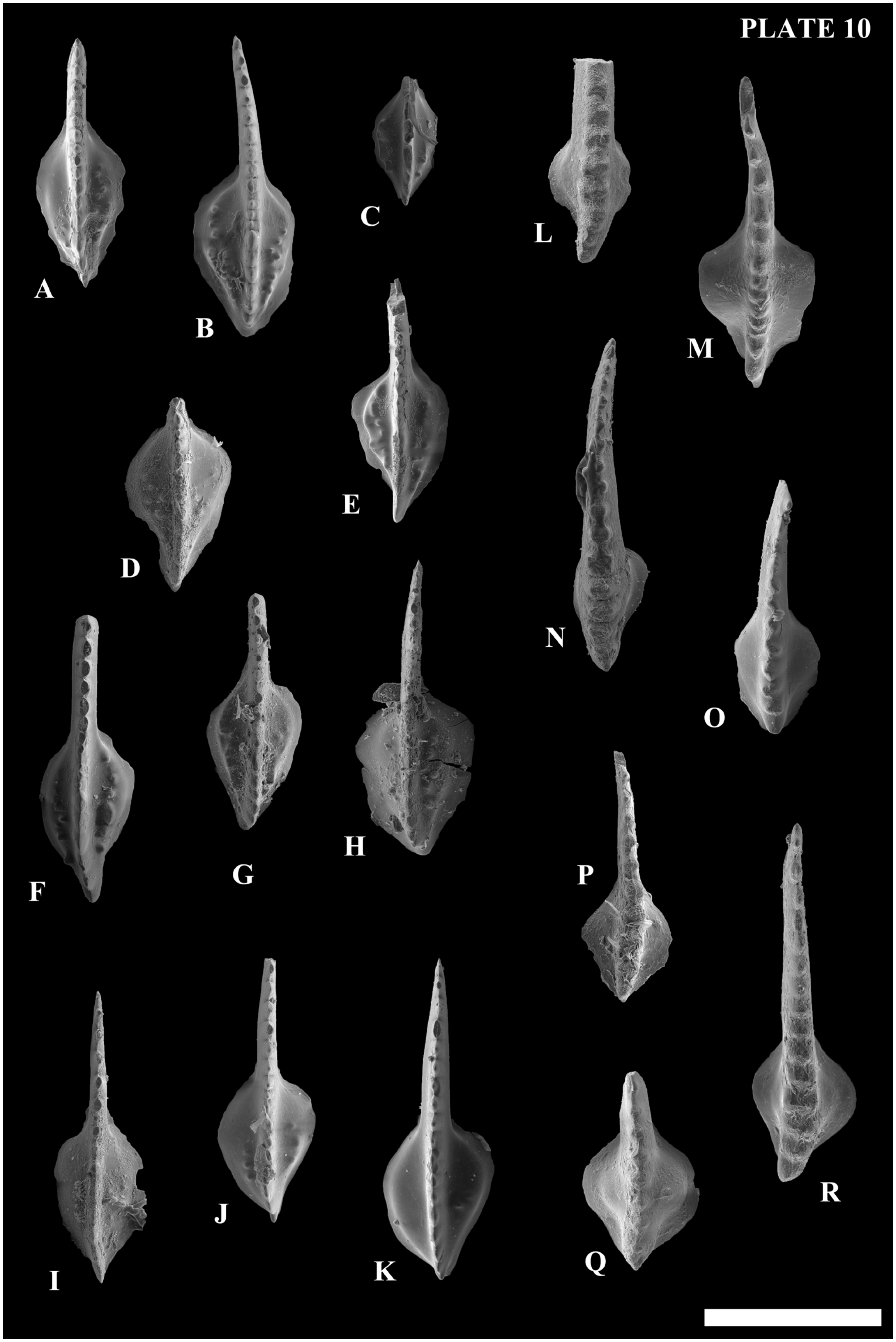
PLATE 10
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PLATE 11 – *Taphrognathus* and *Rhachistognathus*

Figure A – *Taphrognathus varians* Branson and Mehl; Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-21, SUI 141687.

Figure B – *Taphrognathus varians* Branson and Mehl; Moccasin Bend Formation, Boone Group, Moccasin Bend Type Locality, Sample MB-24, SUI 141234.

Figure C – *Taphrognathus varians* Branson and Mehl; Moccasin Bend Formation, Boone Group, Moccasin Bend Type Locality, Sample MB-24, SUI 141240.

Figure D – *Taphrognathus varians* Branson and Mehl; Moccasin Bend Formation, Boone Group, Moccasin Bend Type Locality, Sample MB-24, SUI 141699.

Figure E – *Taphrognathus varians* Branson and Mehl; Ritchey Formation, Boone Group, Fairland Quarry Reference Locality, Sample FQ-10, SUI 141680.

Figure F – *Taphrognathus varians*; Quapaw Limestone, Boone Group, Quapaw Quarry Reference Locality, Sample QQ-5, SUI 141448.

Figure G – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141335.

Figure H – *Rhachistognathus* sp. B; _ Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141337.

Figure I – *Rhachistognathus* sp. B; Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-25, SUI 141261.

Figure J – *Rhachistognathus* sp. B; Lindsey Bridge Member, Pryor Creek Formation, Mayes Group, Ordnance Plant Type Locality (Low Water Dam), Sample LWD-25, SUI 141624.

Figure K – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141202.

Figure L – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Earbob Recreation Area Reference Locality, Sample E-7, SUI 141246.

Figure M – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141209.

Figure N – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-8, SUI 141641.

Figure O – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Spring Creek Recreation Area Reference Locality, Sample SCRA-7, SUI 141210.

Figure P – *Rhachistognathus* sp. B; Hindsville Formation, Mayes Group, Burlington South Reference Locality, Sample BS-25, SUI 141307.

Figure Q – *Rhachistognathus* sp. B; Ordnance Plant Member, Pryor Creek Formation, Mayes Group, Earbob Recreation Area Reference Locality, Sample E-7, SUI 141250.

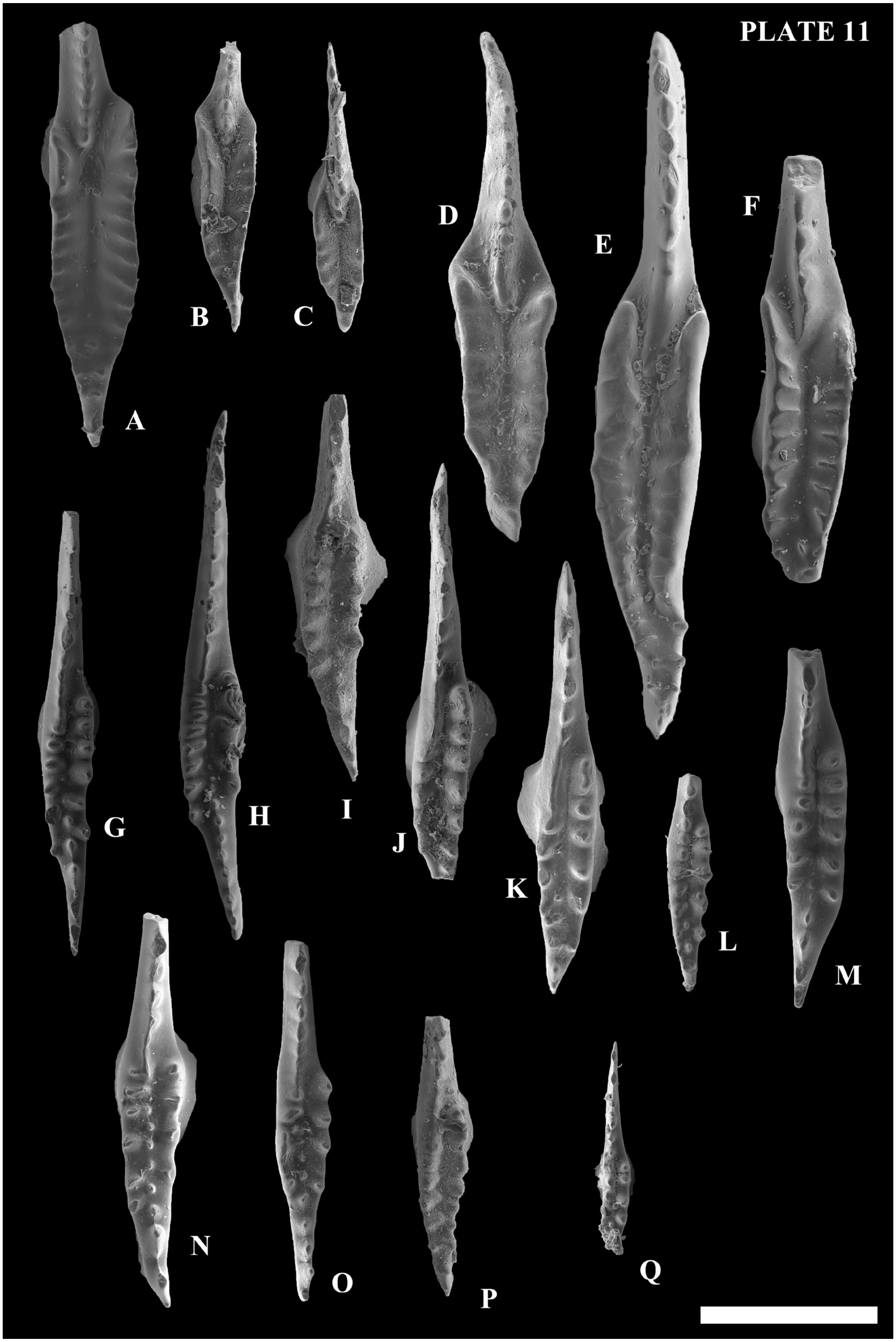
PLATE 11
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VITA

Cory John Godwin

Candidate for the Degree of

Doctor of Philosophy

Thesis: LITHOSTRATIGRAPHY AND CONODONT BIOSTRATIGRAPHY OF THE UPPER BOONE GROUP AND MAYES GROUP IN THE SOUTHWESTERN OZARKS OF OKLAHOMA, MISSOURI, KANSAS, AND ARKANSAS

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